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THE UNIVERSITY OF ALBERTA

STUDENT MISCONCEPTIONS IN CHEMICAL EQUILIBRIUM AS RELATED TO ACHIEVEMENT AND COGNITIVE LEVEL

by

ALAN EDMUND WHEELER

A THESIS
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The undersigned certify that they have read and recommend to the Faculty of Graduate Studies and Research for acceptance a thesis entitled "Student Misconceptions in Chemical Equilibrium as Related to Achievement and Cognitive Level," submitted by Alan Edmund Wheeler in partial fulfilment of the requirements for the degree of Master of Education.

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ABSTRACT

The purpose of this study was to ascertain the relationship between selected student misconceptions in chemical equilibrium and performance on specific tasks involving cognitive transformations characteristic of the concrete and formal cognitive levels of thought.

The study was conducted in two Edmonton high schools on a sample of 99 students enrolled in four chemistry 30X classes during the 1973 spring semester.

Four main test instruments were used. The Misconception Identification Test (MIT), developed for the study, dealt with the following six misconceptions: 1) mass vs. concentration, 2) rate vs. extent of reaction, 3) constant concentration, 4) misuse of Le Chatelier's principle, 5) the constancy of the equilibrium 'constant' and 6) competing equilibria. The Chemistry Achievement Test (CHAT), based on four chapters of the CHEM Study text, provided the measure of achievement in chemistry. The Piagetian Tasks (PT 1, PT 2 and SK6) formed the basis for classification of the sample into the respective level and sublevel of concrete and formal thought. PT 1 and PT 2 were equivalent combinatorial tasks involving five colorless chemical solutions. The three sections of the Skemp Test (SK6), based on ten defined operations, involved transformations of the INRC physical group model. The grade nine SCAT scores were also obtained for the sample.

Item analysis of the MIT revealed that the probability of students choosing the keyed misconception response consistently exceeded that expected by chance alone. Eighty two percent of the sample possessed three or more of the six misconceptions identified.

Correlations between the CHAT scores and the separate Piagetian Task scores were significant at the .05 level. A stepwise regression analysis for the prediction of achievement in chemistry revealed that PT 1 and SK6(2) were significantly contributing predictor variables and together accounted for 58.7 percent of the CHAT variance. Neither the verbal nor quantitative SCAT scores entered into the regression equation.

In terms of cognitive functioning the sample was classified as follows: early concrete (C_1), 3 students; late concrete (C_2), 24 students, early formal (F_1), 61 students and late formal (F_2), 11 students.

The sample was divided into three achievement groups based on the CHAT scores. One-way analysis of variance carried out on all the test scores revealed that, with the exception of the two sections of the Skemp Test, SK6(1) and SK6(3), the three groups differed significantly ($p < .01$).

Correlations between the MIT and the Piagetian Tasks indicated a significant relationship between the number of possessed misconceptions and performance on the tasks. Two of the specific misconceptions were found to be significantly related to cognitive level. Analysis also revealed that the number of possessed misconceptions was related to achievement in chemistry. Three of the six specific misconceptions were found to be related to achievement.

No significant sex difference for either the number of misconceptions possessed or specific misconceptions held was observed.

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CHAPTER I

THE PROBLEM

Introduction to the Problem

The alternate Chemistry 30X course presently taught in Alberta high schools consists of a comprehensive program based on the Chemical Material Study Committee (CHEM Study) (Pimentel, 1963a). The introduction of CHEM Study in the early 1960's has had a pronounced effect on chemistry teaching. Studies on the effect of the CHEM Study course on the teaching of high school chemistry indicate that:

> Students who showed a strong preference for memory of specific facts were at a disadvantage in CHEM Study relative to those who showed a strong preference for fundamental principles, critical questioning of information, and practical application (Atwood, 1967).

CHEM Study incorporates a number of differences from more traditional courses, possibly the most obvious being the shift of the emphasis from descriptive chemistry toward chemical principles to present the change of chemistry over the last two decades. "Chemistry is gradually and logically unfolded, not presented as a collection of facts, dicta, and dogma" (Campbell, 1964).

Approximately forty percent of the present Grade Twelve CHEM Study Course is devoted to chemical equilibrium and related topics. Much of the material in these chapters, in addition to requiring certain basic prerequisite skills and concepts in chemistry, requires a considerable amount of abstraction for a firm understanding of chemical equilibrium. Chemical equilibrium cannot be taught in isolation as it draws heavily on several generalized concepts in science such as kinetic molecular theory (KMT). KMT is only one example of a generalized concept which underlies a number of topics taught in chemistry.

Lantz (1972) in his study emphasizes the importance of the perception of KMT for the understanding of chemistry. He reports:

> There appears to be a significant relationship between student's perception of the kinetic molecular theory and their achievement in chemistry (p. 124).

In addition, Hobbs (1972) in his study on conservation of weight and volume in secondary school students, clearly identifies an important factor to be considered:

> If learning involves interaction between experience and developing thought structures, then the restrictions placed by each of these two upon the other have to be taken into account in the development of science curricula (p. 145).

Hobbs would suggest that certain difficulties or misconceptions possessed by students in major topics in science may better be understood if a sequence of development of concepts relative to physical quantities can be described.

On a much broader basis, increasing emphasis is being placed upon the work of Jean Piaget and the implications of his theory of intellectual development for science teaching. Piaget and his research group have identified a sequence of mental actions leading to the child's understanding of principles and relationships in numerous phenomena commonly taught in science courses (Inhelder and Piaget, 1958).

The developmental sequences which Piaget has identified might well serve as the basis of instruction that is consistent with psychological processes and the existing body of knowledge (Peel, 1964). Piaget is among the few contemporary psychologists who realize the full importance of the existing body of knowledge, its formation and effects.

R. R. Skemp, a British psychologist, writing on reflective intelligence and mathematics, recognizes this in stating:

> A theory is required which takes account (among other things) of the systematic development of an organized body of knowledge, which not only integrates what has been learnt, but is a major factor in new learning . . . (1962).

Skemp's work is firmly based on Piaget's theory and his ideas on reflective thinking in children closely parallel Piaget's notions of formal thought (Harrison, 1967). Skemp has devised a set of test items to measure student performance on the Piagetian transformations of reversibility (negation and reciprocity) and their combinatorial consequences.

A detailed discussion of the principal stages of the development of intelligence as identified by Piaget is not intended here. This study is primarily concerned with the stage characterized by formal operations. This stage, beginning on the average at about eleven or twelve years of age, is characterized by the development of abstract thought operations with which the child, now virtually an adolescent, is capable of reasoning in terms of hypotheses and not only in terms of objects. The formal operational adolescent is capable of constructing new operations of classes, relations, and numbers, a capability not apparent in the concrete operational child.

In order to describe how the adolescent manipulates data which he derives from experiments, Piaget introduces a logical structure or model, the INRC group. The INRC group is an attempt to specify the rules which the adolescent uses in the above transformations. There are four elements in the group: identity (I), negation (N), reciprocity (R), and correlativity (C).

The nature and extent of the use of the INRC transformations serves to distinguish the concrete operational child from the formal operational adolescent. Although the concrete operational child carries out operations on classes, relations or numbers, their structure does not go beyond the level of elementary logical "groupings" or additive and multiplicative numerical groups. During the concrete stage, the child is capable of utilizing the two complementary forms of reversibility (inversion for classes and numbers and reciprocity for relations). However, he is unable to integrate them into the single total system. In contrast, the formal operational adolescent develops a mechanism which results in the integration of inversion and reciprocity.

The adolescent's thought structure is marked by a higher degree of reversibility than is present in previous stages. The two forms of reversibility, negation and reciprocity, become united in a fully operational system (Piaget, 1953). In investigations dealing with equilibrium in the balance (Inhelder and Piaget, 1958, Chapter II) the manner in which subjects deal with the transformations of the INRC group at the concrete and formal substages is illustrated. It is only at the stage of formal operations that the subject is able to understand transformations by inversion (N), consisting of the removal of weights and by reciprocity (R) consisting of putting on equal weights at an equal distance on the other arm of the balance. Here the inverse (N) cancels the original operation, whereas the reciprocal (R) compensates for it without cancelling it. However, N and R have the same final result, that of bringing the arms of the balance back into the horizontal plane. The formal operational subject is able to group transformations into a single system (I, N, R, and NR=C). Moreover, he is able to make use of the equality of products in a more general form than in the multiplication of relations found at the concrete stage. The possibility of reasoning in terms of the group structure implies an understanding of the relationships between the products of two or more transformations: NR=IC, RC=IN, NC=IR, etc. According to Piaget, the acquisition of the INRC group structure characterizes the stage of formal operations in thinking. In the present study an attempt is made to determine whether certain misconceptions in the area of chemical equilibrium are associated with the students' perception of the INRC group as associated with the concrete and formal operational stages.

Another characteristic which distinguishes the formal operational stage from the concrete operational stage is the ability to identify all possible factors relevant to a problem under investigation by forming all possible combinations of these factors, one at a time, two at a time, three at a time, and so on. The individual need no longer confine his attention to what is real but can consider hypotheses that may or may not be true and work out what would follow if they were true. The hypothetico-deductive procedures of mathematics and science have become open to him (Piaget, 1964).

An example of formal operational thought is that carried on by the adolescent in coping with a problem in which he is given five bottles of colorless liquids, of which the first, third and fifth combine to form a yellow color, the second is neutral, and the fourth bleaches out the color (Inhelder and Piaget, 1958, p. 107-122). The problem is to find out how to produce the yellow color given the required solutions, labelled 1, 2, 3, 4, and "a", respectively. At the early concrete stage (C_1), subjects begin by mixing each solution with "a" or by taking them all at once. Although combinations are involved these are the most elementary and limited combinations that operate in multiplicative "groupings" of classes and relations. The idea of constructing combinations two-by-two or three-by-three, etc., does not occur at this level. In the later concrete substage, C_2, the appearance of n-by-n combinations is noted. However, the subject does not as yet discover any system and only tentative empirical efforts are involved. The fact that these combinations are not systematic defines the upper limit of this substage, and subjects typically do not investigate even the six possible two-by-two (with "a") combinations. The cause of the yellow color for the concrete operational subject is still sought in particular elements rather than in their combination. Although some subjects do locate the color by fortuitous means, the roles of other solutions are misinterpreted. The negative effect of solution 4 is also sometimes noted but a specific method of proof is lacking.

The two innovations which appear at the formal operational level are the systematic method in the use of n-by-n combinations and an understanding of the fact that the color is due to the combination as such. Formal stage subjects form their judgements according to a combinatorial system having the form of the sixteen binary propositions. Combinations one-by-one, two-by-two, three-by-three, four or zero of the four base possibilities are taken. This formal mode of reasoning, founded on the combinations of factors, leads the subject to a new conception of the cause of the color. This cause is no longer sought in one or another of the solutions but in their being brought together, in the very fact of their combination.

In the combination of chemical bodies problem, the difference between subjects at the two substages of the formal level, designated F_1 and F_2 respectively, is one of degree. The only innovations of the later substage F_2 are that the combinations, and more particularly the proofs, emerge in a more systematic fashion. Although the results are the same as in substage F_1, they are discovered by a more direct method. This is because the substage F_2 subject makes use of combinations involving substitution and addition with greater efficiency to determine the respective effects of the respective solutions. For example, once the F_2 subject establishes the fact that the color is due to the combinations of solutions 1, 3, and "a", he then replaces solution "a" with solution 2 and then by solution 4 to see if they have equivalent effects. He then goes back to solutions 1, 3 and "a" and adds solutions 2 and 4 alternately to the mixture to determine the effects of these additions. In this manner the F_2 subject arrives at the solution by a more direct and systematic means. This type of reasoning is clearly beyond the concrete operational subject. In their classic study on formal operations, Inhelder and Piaget (1958) describe fully the techniques used in experiments such as the above to ascertain the stage and substage of cognitive development of the subject. Two of the instruments used in the present study closely parallel the combination of colorless chemical bodies task described in *The Growth of Logical Thinking*.[1] These tasks, labelled PT 1 and PT 2, are used as measures of the degree of cognitive development of the students.

Many of the problems that beset students in the area of chemical equilibrium require reasoning at a formal level. Certain misconceptions held by students in this area of chemistry may be related to their inability to adequately deal with certain cognitive transformations associated with formal operational thought.

Statement of the Problem

The main purpose of this investigation is to determine the nature of student misconceptions in chemical equilibrium and ascertain the extent to which certain misconceptions are related to the student's performance on specific tasks involving cognitive transformations characteristic of the concrete and formal operational stages.

Need for the Study

In supporting the need for the study it is assumed that intellectual development follows an ordered sequence—a sequence which, until proof to the contrary, appears to be universal. In an earlier work Piaget (1950) writes:

> Every structure is to be thought of as a particular form of equilibrium, more or less stable within its restricted field and losing its stability on reaching the limits of the field. But these structures, forming different levels, are to be regarded as succeeding one another according to a law of development, such that each brings about a more inclusive and stable equilibrium than at the preceding level. Intelligence is thus only a generic term to indicate the superior forms of organization or equilibrium of cognitive structurings (p. 16).

Thought develops through a series of stages where new mental structures emerge from the old ones by means of the dual processes of adaptation: assimilation and accommodation. The development of intelligence involves a progressively more complex balancing or 'equilibration' of these two processes with each stage of schemata containing the preceding stage within its organization. Faced with novel experiences the subject seeks to assimilate them into his existing mental framework.

> Mental development is more than a mere accumulation of isolated and unrelated experiences; it is an hierarchical process with the later acquisitions being built upon and at the same time expanding upon the earlier ones (Ginsburg and Opper, 1969).

Hence it would seem to serve little purpose to attempt to teach chemical equilibrium, or any other abstract notion which requires the existence of reasoning at a formal operational level, without some awareness of the current cognitive level of the student. Three of the instruments used in the present study are used as measures of the cognitive level of the student. Certain misconceptions that may be present concerning chemical equilibrium are also investigated. Any instructional strategies that may be devised to promote a better understanding of chemical equilibrium must clearly be based on a clear delineation of the conceptual problems encountered by students in this area.

Ausubel (1965) supports the necessity for teachers to be aware of the student's developmental level of cognition, if effective teaching is to be achieved in science. He writes:

> In my opinion, the most significant advances that have occurred in recent years in the teaching of such subjects as mathematics, chemistry, physics, and biology have been predicated on the assumption that efficient learning and functional retention of ideas and information are largely dependent upon the adequacy of cognitive structure. That is, upon the adequacy of an individual's existing organization, stability, and clarity of knowledge in a particular subject matter field.

It should be noted that the concept of cognitive structure to Ausubel refers more to the structure of the existing subject-matter concepts than to the structure of cognitive operations in a Piagetian sense. However, while Ausubel and Piaget differ in their views on the nature of cognitive structure, they would both agree that it is only when some degree of awareness of the student's current level of cognitive development is achieved that experiences can be made available to facilitate development.

> Hence it is largely by strengthening relevant aspects of cognitive structure that new learning and retention can be facilitated. When we deliberately attempt to influence cognitive structure so as to maximize meaningful learning and retention, we come to the heart of the educative process (Ausubel, 1965).

The relationship between student achievement in chemistry and performance on selected problems involving cognitive skills needs to be investigated. There is little justification to be found in assuming uniformity of intellectual development among students in any given classroom. Unfortunately, much of the science teaching one observes all too frequently reflects such an assumption. Recent studies in science teaching based on Piaget's theory of intellectual development (Buell and Bradley, 1972; Bass and Montaque, 1972) show that many students do not always function at the cognitive level of which they are capable.

The study conducted by [illegible] and Montaque (1972) concerned two problems from the general area of physical science: equilibrium in a simple see-saw type balance; and equilibrium of a cart on an inclined plane. The purpose of the study was to translate Piaget's developmental sequences into an hierarchy of instructional objectives and instructional materials for the two problems. Objectives consistent with Piaget's findings on the balance and the inclined plane were evaluated through classroom trials with 133 ninth-grade physical science students. It was expected that the ninth-grade students, most of whom were either 14 or 15 years of age, would be capable of thinking at the formal or substage F_2 level. Data were collected by means of a pre- and post-test designed for the study and through analysis of the student's responses on the self-instructional sequences. Results on the pretest showed that for the balance and inclined plane problem only 45 and 44 percent, respectively, of the students were at substage F_2. The percentage of the sample operating at substage F_2 on the balance increased from 45 percent on the pretest to 75 percent on the posttest. For the inclined plane problem the percentage of students operating at substage F_2 increased from 44 percent to 61 percent.

The results of the Bass and Montaque study suggest that the hierarchy of objectives derived from Piaget's analysis of the balance problem and the instructional materials based on these objectives were effective with the ninth grade sample. However, the objectives for the inclined plane were not found to be hierarchical. These findings strongly suggest that, where feasible, the instructional sequence should parallel the sequence of development of the child's area. Further studies to supplement Piaget's more general descriptions of child thought on scientific concepts would be an important contribution to science education. The present study attempts to ascertain the role of formal reasoning as seen by Piaget in the specific area of chemical equilibrium at the high school level.

Piaget's work is important for the psychology of cognition especially as it pertains to children and adolescents because it identifies, at least tentatively, significant changes in cognitive capacities, processes, and phenomena as a function of age, experience, and intellectual sophistication. Science curricula such as CHEM Study increasingly de-emphasize concrete and empirical methods while requiring a greater degree of abstraction and propositional thinking by the student. This suggests an even greater need for the science educator to clearly distinguish between the chronological age and the current level of cognitive development of his students.

The concept of chemical equilibrium has long been recognized as one of the most important principles in chemistry. If a relationship between student misconceptions in chemical equilibrium and ability to deal with certain logical cognitive transformations can be established, teachers may be better equipped to anticipate and perhaps minimize problems while teaching specific sections on chemical equilibrium. The identification of misconceptions in chemical equilibrium may allow specific instructional strategies to be devised which result in a more efficient treatment of the topic.

Further, the extent to which certain misconceptions occur in chemical equilibrium may reveal the need for extensive beforehand review of certain prerequisite concepts in this area. It may also reveal a need for review of more fundamental concepts like Kinetic Molecular Theory (KMT). While concepts such as KMT are not unique to chemistry, they are nevertheless necessary for a firm understanding of the discipline. Problems arising from questions involving quantitative aspects of chemical equilibrium may suggest certain deficiencies in basic mathematical operations and skills. Experiences may then be offered to the students to facilitate development in these areas.

The approach used in this study, together with the type of instruments used, may well prove useful in identifying misconceptions held by students in other areas of high school science teaching. The basic design of the instruments used in the study is independent of the subject content and could be readily adapted for study in other areas.

If research in science teaching is to be truly helpful it must be concerned with detailed curriculum specifications and prescriptions (Belanger, 1964). In this regard it should be noted that Piaget is basically concerned with describing the "generalized knower" (the epistemic subject) and while such description sheds profound insight on epistemological problems, it lacks the fine-structure required for use in the science classroom. The developmental sequences outlined by Piaget can only serve as a guideline for detailed curriculum development. The studies of Bass and Montaque (1972), described earlier, and of Ravens (1967), dealing with the concept of momentum in children, stand out as examples of the kind of research so badly needed in this area.

The approach taken in the present study to identify and classify types of misconceptions in chemical equilibrium serves a two-fold purpose. First, it determines specific misconceptions and ascertains the extent to which they occur. Second, by virtue of requiring students to state their reasoning for their responses, greater insight into the nature of misconceptions present may be possible. This procedure serves to distinguish between those students who incorrectly answer a question because of a misconception and those who answer incorrectly out of ignorance of the subject matter.

The present study may further offer suggestions as to the most efficient method of presenting the topic of chemical equilibrium to high school students. If, for example, misconceptions are found to be prevalent in various kinds of equilibrium problem as covered in the present chemistry course, one may question the merits of the essentially deductive CHEM Study approach taken to this topic. The adoption of a more inductive approach to chemical equilibrium involving many more specific examples of equilibria may have merit as a psychological basis for presentation.

Definition of Terms

Chemical Equilibrium:[2] A state of affairs in which a chemical reaction and its reverse reaction are taking place at equal rates so that the concentrations of reacting substances remain constant. Specifically those examples of chemical equilibrium which will be considered deal with homogeneous gas reactions, phase changes, and aqueous solutions of ionic solids.

INRC Group Model (Piaget): The group of four transformations: identity (I), negation (N), reciprocity (R), and correlativity (C), corresponding to certain fundamental structures of thought at the formal level. For purposes of the study the INRC group model refers to the physical INRC group as defined by Flavell (1963, p. 217) and clarified by Parsons (1960).

Misconception: The act whereby a student, through incorrect reasoning, arrives at an inaccurate or erroneous answer to a problem as measured by the Misconception Identification Test (MIT). Misconceptions can be of three types:

Type I	- The chosen response is correct but the stated reasoning is incorrect, or not applicable.
Type II	- The chosen response is incorrect but the stated reasoning is correct as far as it goes.
Type III	- Both the chosen response and stated reasoning are incorrect.

The six major misconceptions under investigation are the following:

Misconception 1. Mass versus Concentration —
- inability to distinguish between the concepts of mass and concentration.

Misconception 2. Rate versus Extent —
- inability to distinguish between how fast a reaction proceeds (rate), and how far (extent) the reaction goes.

Misconception 3. 'Constancy' of the Equilibrium Constant —
- uncertainty as to when the equilibrium constant is in fact a constant.

Misconception 4. Misuse of Le Chatelier's Principle —
- the application of 'Le Chatelier type' reasoning in inappropriate situations.

Misconception 5. Constant Concentration —
- inability to appreciate that certain substances display a fixed or constant concentration in certain chemical reactions.

Misconception 6. Competing Equilibria —
- inability to consider all possible factors affecting the equilibrium condition of a chemical system.

Misconception Identification Test (MIT): A 30 item, 4 distractor multiple choice, open book test based on examples of chemical equilibria constructed for the study which requires students to predict the effect of manipulating variables on the equilibrium condition of several chemical systems. The MIT consists of six subtests corresponding to each of the six major misconceptions (1-6) defined above. In addition some questions require the student to justify his prediction for several items by stating the reasoning involved in his choice and the law or principle used in arriving at his responses. The MIT is presented in Appendix A.

Misconception Score: Refers to the score a student obtains on a subtest of the Misconception Identification Test (MIT) when the MIT is keyed according to a given misconception.

Performance Score: Refers to the score a student obtains on a subtest of the Misconception Identification Test (MIT) when the MIT is keyed accurately in a chemical sense.

The performance score and the misconception score for each student on each subtest of the MIT are used to determine whether or not the student possesses a particular misconception. Performance and misconception scores are more fully discussed in Chapter IV.

Operation: Any representational act which is an integral part of an organized network of related acts (Flavell, 1963, p. 166). Operations constitute among themselves closed systems whose most important characteristic is their reversibility. The isolated operation cannot be the proper unit of analysis, because it gains its meaning from the system of which it is a part.

Piagetian Tasks (PT 1 and PT 2, SK6): Refer to three of the test instruments used in the study. These are the combination of colorless chemical bodies tasks, designated PT 1 and PT 2, and the Skemp Test (SK6). Performance on these tasks is used as a measure of the student's level of cognitive development. PT 1 and PT 2 are presented in Appendix D and SK6 is presented in Appendix C. (The Piagetian tasks are discussed more fully under the section dealing with experimental procedure in this chapter.)

Reversibility: The possibility of performing a given action in a reversed direction. Its two chief forms are: negation (not male = female) and reciprocity (not better = worse). Reversibility is the basic criterion of an underlying operational structure.

Transformation: The name given to the process by which operations can be changed in form. For example, the inverse or negation of the operation of adding weight to a balance is the removal of that weight. The system contains two distinct and different operations, p and q, which have exactly equivalent outcomes and two other operations, p* and q*, which nullify or undo p and q respectively.

The four transformations within this system of operations are as follows:

1. Identity (I): The 'null' transformation which changes nothing in the operation on which it is performed. I (p)=p, I(q)=q, I(p*)=p* and so on. For example, in dealing with the problem of the scale balance the identity transformation of the operation of adding weight to the pan (p) is the original operation itself. Identity does not change the original operation and is similar to the mathematician's unity.

2. Negation or Inversion (N): The transformation which results in cancelling or undoing the original operation. N(p)=p*, N(q)=q*, N(p*)=p, and so on. Here the inverse or negation of the operation of

adding weight to the pan is the removal of that weight from the pan.

3. Reciprocity (R): The transformation, having the same ultimate effect as negation, which compensates or neutralizes the effect of an operation by a symmetrical, equal and opposite counter force. R(p)=q*, r(q)=p*, r(p*)=q, and so on. For example, the operation of adding weight to the right-hand arm of the balance is the reciprocal transformation of adding weight to the left-hand one. Although the reciprocal has the same effect as the negation transformation, that of restoring the scale balance to its original equilibrium, it is achieved by a different route. In this sense reciprocity is a different type of reversibility.

4. Correlativity (C): The product of negation and reciprocity or cancelled compensation. C(p)=N(R[p])=q, C(q)=p, and so on. Here the negation of the reciprocal transformation carried out on the operation of adding weight to the right balance pan results in a net effect of removing an equal weight from the left pan. Here C=NR (and C=RN). Summing up we see the above transformation form a four group such that: the correlative C is the inverse N of the reciprocal R, so that C=NR (and C=RN). Likewise R=CN (or R=NC) and N=CR (or RC). Also I=RCN (or CRN).

Research Hypotheses

As the study is seen to encompass two main areas of concern, the hypotheses are stated accordingly:

Hypothesis 1.0: The rate of incidence of specific misconceptions in chemical equilibrium consistently exceeds that expected by chance.

Hypothesis 2.0: There is no significant relationship between student achievement in chemistry and performance on selected Piagetian tasks.

The following null hypotheses series depend upon the relationship between the performance on selected Piagetian tasks and student achievement in chemistry. If a relationship is found to exist between achievement in chemistry and performance on the Piagetian tasks, its effects on the following null hypotheses must be taken into consideration. If no relationship is found, hypotheses 2.1, 2.2, 2.3, and 2.4 will be tested separately.

Hypothesis 2.1: There is no significant relationship between the number of misconceptions a student demonstrates in solving selected problems in chemical equilibrium and performance on selected Piagetian tasks.

Hypothesis 2.2: There is no significant relationship between specific misconceptions in chemical equilibrium and performance on selected Piagetian tasks.

Hypothesis 2.3: There is no significant relationship between the number of student misconceptions in chemical equilibrium and achievement in chemistry.

Hypothesis 2.4: There is no significant relationship between selected misconceptions in chemical equilibrium and achievement in chemistry.

Associated Questions

In addition several associated questions which will be examined in this study are:

1. Is there a significant difference between male and female students in the number of misconceptions in chemical equilibrium?
2. Is there a significant relationship between specific misconceptions and the sex of the student?
3. Is the degree of student misconceptualization in chemical equilibrium related to mathematical ability?

Experimental Procedure

The Sample

The sample for the main study comprised 99 students enrolled in the Chemistry 30X program in two high schools in the Edmonton Public and Separate School Systems. In all, five classes were involved during the 1973 spring semester.

Testing Procedure

Four main test instruments were used in the study:

1. The Misconception Identification Test (MIT), described earlier, which asked students to predict the effect of various variables on the equilibrium condition of several chemical reactions. The MIT is used as a measure of both the nature of (that is, identification of) and degree of misconceptualization in the area of chemical equilibrium.

2. Chemistry Achievement Test (CHAT): A 33 item multiple choice, 5 distractor open book achievement test based on Chapters 7, 8, 9, and 10 of the CHEM Study Text. The CHAT devised by Lantz (1972) has a reliability of 0.71 (KR20) and deals with the following topics: "Energy Effect in Chemical Reactions," "Equilibrium in Chemical Reactions," "The Rate of Chemical Reactions," and "Solubility Equilibria."

The CHAT is presented in Appendix B.

3. Skemp Test (SK6, Part II): This test, devised by R. R. Skemp of Manchester University, consists of 45 geometric test items based on ten clearly defined operations. Prior to the administration of the SK6, Part II, students are given a practice sheet and a demonstration sheet illustrating these operations. This is followed by the SK6 (Part I) test used to gain further familiarity with the operations. An answer sheet is provided for SK6 (Part I), and questions concerning the operations are answered prior to the administration of the SK6 (Part II). Items on the SK6 (Part II) involve transformations of reversibility, both negation and reciprocity, and combination in addition to items requiring various types of combinations of these transformations. Performance on the three sections of the Skemp Test is used as a measure of the student's ability to use the INRC group model. The Skemp Test is presented in Appendix C.

4. The combination of Colorless Chemical Bodies Tasks, PT 1 and PT 2.

Piagetian Task I (PT 1) is based on the combination of colorless chemical bodies task described in Inhelder and Piaget (1958, p. 107-122). The task requires the subject to produce a yellow color by manipulating five colorless numbered chemical solutions. The solutions are numbered as follows: (1) dilute sulphuric acid; (2) water, (3) hyrogen peroxide; (4) sodium sulphite and solution 'a' containing potassium iodide. Since the peroxide solution will oxidize potassium iodide in an acid medium, the mixture of solutions 1, 3, and 'a' will yield a yellow color. The water solution (2) is neutral, whereas the sulphite solution (4) will bleach the mixture of 1, 3, and 'a'. The student is asked to record his approach to the problem in a step-by-step fashion on a separate sheet provided. Further, he is asked to investigate the solutions as much as he can to determine the effect of each one. As such PT 1 involves combinational operations in their general form and includes notions relative to inversion and reciprocity. In a manner similar to the classical investigation carried out by Inhelder and Piaget (1958) the student's method and approach used to solve the task will form the criteria for evaluation of individual performance on the PT 1. A more detailed discussion of these criteria is presented in this chapter. PT 1 is presented in Appendix D.

Piagetian Task 2 (PT 2) is a task devised for the study which closely parallels PT 1 in its format. PT 2 involves the combination of five labelled colorless, chemical solutions to yield a yellow coloration. The solutions are numbered (1) water; (2) starch; (3) sodium sulphite; (4) chlorine water; and solution 'b' containing potassium iodide. The chlorine water will oxidize the iodide solution resulting in the mixture of 4 and 'b' producing the yellow color. As in PT 1 the sulphite solution (3) has the effect of bleaching the mixture 4 and 'b', the water solution (1) has no effect. The starch solution (2) forms a deep blue color with 4 and 'b'. The sulphite solution (2) also bleaches the deep blue color.

The students are required to record their solution to PT 2 on the separate sheet provided. PT 2 is presented in Appendix D. In addition, the Grade Nine Co-operative School and College Ability Test, Form 3A (SCAT) scores were obtained for each individual, where possible.

Pilot Study

Pilot projects involving the Misconception Identification Test (MIT) and two of the Piagetian Tasks were conducted prior to the formal administration of the test instruments. The initial form of the MIT was distributed to several experienced chemistry teachers and professors in order to assess its accuracy, clarity, degree of difficulty and relevance to its intended purpose. After incorporating suggested changes deemed necessary by the consultants, the MIT was then administered to three Chemistry 30X classes in order to further refine the instrument. An assessment of the reliability and validity of the MIT was then made on the basis of an item analysis for all questions on the instrument. This resulted in rephrasing the wording of several items in accordance with the CHEM Study terminology together with the decision to make the MIT an open-book examination.

In a similar manner the two Piagetian tasks (both are forms of the Combination of Colorless Bodies Task) were pretested using the same students. Following the correction of certain difficulties associated with the directions for performing these tasks, final versions for both forms were developed. To gain familiarity with the administration and use of both the Chemistry Achievement Test (CHAT) and the Skemp Test (SK6) these were given to the 62 students in the three Chemistry 30X classes used in the pilot study.

Sequence of ~~Test~~ Administration

In the main study the Chemistry Achievement Test (CHAT) was administered first, followed by the Misconception Identification Test (MIT), the Skemp Test (SK6) and the two Piagetian Tasks (PT 1 and PT 2).

Both the CHAT and the MIT were administered following completion of the topics covered in the tests being taught in the regular classroom setting. As the Skemp Test SK6 and the Piagetian Tasks (PT 1 and PT 2) were deemed independent of the specific chemistry content covered, they were administered approximately one week later.

Delimitations

Since the Chemistry Achievement Test (CHAT) deals with only four of the eight chapters in the Chemistry 30X course, any generalization regarding chemistry achievement will have to be restricted to the topics covered by the CHAT. While teacher methodology and degree of emphasis given to the topics covered by the CHAT were not controlled, the participating teachers were asked for this information in order to detect any obvious omissions or irregular situations.

The nature of the Piagetian tasks, mainly of the non-verbal, paper and pencil variety, necessitates the delimitation of any generalizations regarding the student's performance on these tasks to those situations tested. While the investigator notes that certain cognitive skills may be more relevant to chemical equilibrium, an overemphasis on the specificity of these competencies should not be encouraged. Further, the application of the INRC model to the chemical equilibrium problem situations investigated in this study only serves as an example of one area of application of formal operations in adolescent thinking. A more definitive study to fully investigate the rôle of each of the INRC transformations is clearly beyond the scope of this study, although the approach taken in the present study may reveal some guidelines for such research.

Limitations

One limitation of the study concerns the possible oversimplification of the nature of the misconceptualization as measured by the Misconception Identification Test (MIT). The items in the MIT were designed to elicit certain types of misconceptions as perceived by the investigator, in consultation with experienced people in the field. The misconceptions identified by this instrument are those which are deemed critical to a firm understanding of chemical equilibrium at the high school level, and not necessarily exhaustive of the domain of possible misconceptions in this area.

A further limitation concerns the validity and reliability of the test instruments used. While the reliability of both the Chemistry Achievement Test (CHAT) and the Misconception Identification Test (MIT) can be assessed statistically, there exists no statistical means of assessing the validity of the series of Piagetian Tasks used to measure the level of cognitive functioning of the students. However, the tasks closely parallel those used in classical studies (Inhelder and Piaget, 1958) and the Skemp Test SK6 has been used in other studies (Harrison, 1967). Both the feasibility and appropriateness of these tasks were discussed with Piagetian experts.

CHAPTER II

THEORETICAL FRAMEWORK AND RELATED RESEARCH

Introduction

In order to place the present study in theoretical perspective, Piaget's theory of cognitive development is outlined here. Special emphasis is placed upon the INRC group logical model, its role in formal thought and its applicability to the present study. The review is presented from the point of view of a chemistry teacher who is primarily concerned with the practical implications of the model for classroom teaching and learning situations.

The second part of the chapter is devoted to a review of research studies considered to be particularly relevant to the investigation being reported.

Piaget's Cognitive Theory of Intellectual Development

Perhaps the most important concept in Piaget's theory of cognitive growth is the "schema." By this term Piaget refers to an internalized mental representation of a particular action, an internal structure which is linked with a certain pattern of behavior. Piaget uses the analogy of a mathematical "operator," and in fact refers to the highest levels of mental organization as "operational schema" or "operations."

The development of mental structures is conceived as the progressive internalization and symbolization of action. Through a series of more and more complex stages, the child gradually is able to free his thought processes from the motor activities upon which they are based. Piaget sees these internal structures as hierarchically organized. The earliest schemata are physical actions upon the child's immediate environment. These become internally represented as the child moves through symbolic and perceptual representations of action to fully abstract mental concepts. Each stage of schemata contains the preceding stage within its organization but the earlier stage has been further broadened, complicated, and enriched by interaction with other schemata. The new level is a sensitively balanced "equilibrium" of interlocking mental structures.

Thought develops out of an encounter between the growing child and his environment. Piaget employs the biological concept of "adaptation" to account for change and growth in mental life. The two complementary principles of adaptation are "assimilation" and "accommodation." In assimilation, the child has an existing schema or rule of action towards a particular group of objects. In accommodation he must modify his existing schema to incorporate new objects into his domain. The critical difference between the two processes seems to be in the degree of discrepancy between the newly discovered object and the old schema. The only real change in behavior, and thereby in mental structure, occurs in accommodation. Nevertheless, adaptation is a balancing off of both assimilation and accommodation. The result at any moment is a "semi-mobile equilibrium," an equilibrium in the sense of a balance between the two processes, and semi-mobile in the sense that it is always subject to reorganization whenever discrepancy forces the child to move to a new stage.

In a child's development of operational structures, the basis of knowledge, Piaget has distinguished four main stages: a sensori-motor, pre-verbal stage, extending through approximately the first eighteen months of life; a pre-operational stage extending from about eighteen months to about seven years; a concrete operations stage from about seven years to about eleven or twelve years; and a formal operations stage which begins at about eleven or twelve years of age. Although the order of the developmental stages is constant, the chronological ages corresponding to the stages vary a great deal from culture to culture and individual to individual (Dodwell, 1960; Price-Williams, 1961).

Between the birth of the infant and the ages of one and one half to two years, the child moves through six substages of sensori-motor intelligence. The scope of this development may be seen by comparing the earliest period where the child has only a few reflexive schemata at his command, and the final period where he is able to imitate an absent model, search for and find a hidden object and show considerable evidence of internal mental activity. He realizes that objects which are no longer in the immediate here and now still continue to exist, but his appreciation of them is tied to concrete actions.

From two to four years, the child increases his capacity for stable internal images of external events and actions. Imitation, play and language development are the primary achievements of this period. Thought, however, is "transductive"; the child reasons from particular to particular and his symbolic activity is frequently very idiosyncratic. In the "intuitive" phase, he begins to show beginning of logical thought, but his thinking is highly unstable and is tied to perceptual arrangement. The issue of centration and decentration of thinking is relevant to this period, and is most clearly illustrated by reference to Piaget's studies of the concept of number. Nonconservation occurs at this stage with respect to number, space, duration, quantity, classes, series, weight and volume. The child's concrete thought processes are said to be irreversible.

Between the ages of seven to eight and eleven or twelve, an important development of thinking, not yet separated from its concrete context, is formed. Examples of operations developed in this stage of concrete operations include those of classification and of ordering. Included are operations of spatial and temporal nature, operations of the elementary logic of classes and relations, and operations of elementary mathematics (associativity, closure), geometry and physics. All operations are concrete in the sense that they operate on real objects.

The yet incomplete systems of operations are characterized by two forms of reversibility: negation, in which a perceived change is seen to be annulled by its corresponding negative thought operation; and reciprocity, in which, for example, "being a foreigner" is seen as a reciprocal relationship and before-behind spatial relationships are seen as relative. At this level, the two forms of reversibility are employed independently of one another.

The capacity for formal, logical, abstract thought appears at about age eleven or twelve. Reasoning about the "possible," about ideas and events which are in the past, the future, or the imagination, is now within the person's scope. The ability of the adolescent to transcend the immediate here and now is on a theoretical basis and therefore distinct from the child's fantasy and imagination found in earlier periods. Such conditional concepts as proportions, probabilities, permutations, and combinations are available to the adolescent, as is the capacity to perform "logical experiments," to formulate hypotheses and test them, and to do all this without necessary reference to concrete materials or images. The adolescent's system of mental operations, now highly flexible, has reached a high degree of equilibrium. According to Piaget, thinking now manifests the qualities of pure mathematics or logic.

The essential attribute of formal thought is its orientation towards the possible and hypothetical (Flavell, 1963, p. 212). One manifestation of this orientation is the adolescent's tendency to explore all possibilities by subjecting the problem variables to a combinational analysis. In the present study the Piagetian Tasks (PT 1 and PT 2) involving the combination of colorless liquids clearly illustrates how the adolescent deals with such problems (Inhelder and Piaget, 1958, p. 107-122).

For illustrative purposes let p represent the formation of the yellow coloration produced in the first Piagetian Task (PT 1). $\bar{p}$ represents the absence of the yellow color. If q represents the water solution used in the task, then $\bar{q}$ represents its absence and the following is seen to occur. As the adolescent begins experimentation with the 16 possible combinations involved in the task he may correctly note that the yellow color is present when the water solution is present in the mixture (i.e., p.q). The younger child might conclude (incorrectly in this case) that the water solution is responsible for the yellow color (i.e., that p implies q). The adolescent on the other hand, aware of the totality of possibilities in the task, proceeds to test the possibilities by further experimentation. He establishes that

$p.\bar{q}$, $\bar{p}.q$ and $\bar{p}.\bar{q}$ also hold and therefore correctly concludes that the water solution q is causally irrelevant to the yellow coloration p. In a similar manner other variables in the solution tasks (the acid solution, the color-inhibiting solution, etc.) are fully investigated by the adolescent before conclusions are drawn. The Inhelder and Piaget volume on adolescent reasoning (1958) abounds with instances of this kind of problem-solving strategy. In extensive experiments involving the combination of solutions task they have categorized subjects according to both concrete and formal operations stage in addition to the substages at each level. Both Piagetian tasks (PT 1 and PT 2) are closely related to the classical experiment on colorless solutions conducted by Inhelder and Piaget. The criteria used to determine the cognitive level of students in the experiments conducted by Inhelder and Piaget (1958) form the basis for evaluation of PT 1 and PT 2 used in the present study.

The basic criteria for determining performance on the Piagetian tasks (PT 1 and PT 2) are as follows:

Early Concrete Stage (C_1)

In the early concrete stage (C_1) the only spontaneous reactions of the student are either to associate each one of the solutions 1 to 4 in turn with solution 'a' or to take all four at the same time. At this level the student does not think of attributing the yellow color to the combination of several solutions as such. Rather he thinks of the color in terms of a single solution itself.

The idea of constructing combinations two-by-two or three-by-three, etc., does not occur to students at this level. Further, they are unable to account for the effect of solution 4 (the color-inhibiting solution).

Late Concrete Stage (C_2)

In the late concrete stage, student reactions are similar to those of C_1 but more advanced. The most visible progress is the appearance of n-by-n combinations. However the students still do not discover any system and only tentative empirical efforts are involved.

Students at the level of C_2 usually begin by multiplying each solution by solution 'a'. They then spontaneously use two-by-two or three-by-three combinations (each time with solution 'a'). The yellow color is still associated with particular solutions and not combinations of solutions. Students here do not carry out a systematic investigation of even the six possible two-by-two combinations of solutions with solution 'a'.

The fact that combinations performed by students at this level are non-systematic defines the upper limit of this stage. Although many students discover the cause of the yellow color and even the negative effect of solution 4, it is only by direct manipulation and lacks any specific method of proof.

Early Formal Stage (F_1)

At the level designated F_1 the major developments are the emergence of a *systematic* method in the use of n-by-n combinations, and an understanding of the fact that the color is due to the combination of the solutions. The six possible 2x2 combinations (with solution 'a') are easily attained by students.

Once the yellow color is found (solutions 1 and 3 and 'a') the student operating at the F_1 level is not content with a single solution to the problem and investigates other combinations. Students can distinguish between solutions 2 (neutral) and 4 (negative effect) by the use of addition and substitution combinations.

In contrast to the earlier concrete stages students at the early formal stage perceive the totality of combinations possible and investigate the problem. However in practice the methods used by many students at this level are seen to involve redundant combinations and lack certain refinements present in the late formal stage (F_2).

Late Formal Stage (F_2)

The difference between stages F_1 and F_2 is only one of degree. Students at the level designated F_2 are seen to be more systematic than at F_1 and the solutions for the task and the effects of particular solutions are arrived at by a more direct method. As with students at the early formal stage substitution and addition combinations are used to investigate the different effects of solutions 2 and 4. However their use at this level is more sophisticated and they are carried out with greater speed.

Students at the late formal level are fully aware of the inherent possibilities of the solutions problem and are capable of devising a *minimum strategy* to arrive at the full solution.

The INRC Group Model

The INRC group model is an attempt to specify the rules which the adolescent uses in manipulating or transforming functions. The four rules or transformations are: identity (I), negation (N), reciprocity (R) and correlativity (C). A subject's ability to apply these transformations as a group in problem-solving situations provides the basis for cognitive level categorization.

It should be pointed out that two forms of the INRC group have been distinguished: the logical INRC group and the physical INRC group (Parsons, 1960). The logical INRC group deals with content consisting of propositional statements as described by Piaget (1946b), and Inhelder and Piaget (1958). The content of the other, the physical INRC group, entails physical operations (Flavell, 1963, p. 217). The need for distinction, according to Flavell, arises from the differences in the logical meaning of the two transformations of negation and reciprocity in the two contexts. For purposes of the present study the INRC group model refers to the physical INRC model as seen by Flavell (1963, p. 217) and as defined earlier. The negation (or inverse) operation, as its name suggests, involves the literal cancelling or undoing of an operation. Although it ultimately has the same effect as the reciprocal operation, it is achieved by a different route. The compensating or neutralizing effect produced by the reciprocal operation is a result of the introduction of a symmetrical and equal and opposite counterforce. That is, in the physical INRC model, negation directly annuls or undoes the operation while its reciprocal leaves the operation untouched by neutralizing its effect.

The INRC model as used in the present study serves only as a theoretical model or schema for the description of student reasoning in the area of chemical equilibrium. Performance on both the Skemp test (SK6, Part II) on the Piagetian tasks (PT 1 and PT 2) are deemed measures of the students' ability to use the INRC model. Piaget and his associates in dealing with problems involving physical systems of the (p p* q q*) type have shown that their formal-operational subject is capable of identifying all four transformations of the INRC group and further that he views them as a system, with each operation bearing a specified relation to each other.

In experimentation involving problems of mechanical equilibrium (the hydraulic press, the balance) certain types of conservation, probability and others, Piaget illustrates the dependency of reasoning at the formal level of the INRC group model. Only at the level of formal operations do the two forms of reversibility (negation and reciprocity) become truly integrated into a single system.

The nature of the physical INRC group structure is well illustrated in the snail problem (Inhelder and Piaget, 1958, p. 318-319; Piaget, 1946b, Chapter 5). In this experiment, a snail is set in motion on a plank which can be moved either in the same direction as the motion of the snail or in the opposite direction. If we let p represent a left to right movement of the snail on the board for a distance X, then p* represents the inverse, right to left movement of the snail on the board for a distance X. Hence p* returns the snail to the point of origin. Similarly q represents a left to right movement of the board on the table for a distance X and q* represents the inverse movement of the board on the table. Here the snail is assumed to be resting immobile on the board. The INRC transformations of these four operations constitute an example of the "physical INRC group."

For the snail-board operations, the identity transformation (I) leaves them unchanged. The negation (N) reverses the direction of motion. R reverses the directions and interchanges the two objects, the snail and board. For example, R transforms p to q* and p* to q. In other words the reciprocal of the snail moving from left to right on the board (p) is the motion of the board from right to left. As we have seen, the net effect of the reciprocal transformation is identical to that produced by the negation or inversion transformation.

In a similar fashion the correlative transformation can be shown to be the composition of N and R. To apply C the operation is first transformed by negation (N) followed by its reciprocal R, i.e., C(p)= N(R[p])=q.

Easley (1964) presents a more complete analysis of the snail problem in terms of the physical INRC group. Here the focus of the investigation was on the connection between the INRC group and the snail problem to see how this abstract group applies to a particular problem which can be tested in the classroom.

The present study is concerned with the application of the physical INRC group transformations to problems involving chemical equilibrium. Consider the example of two chemical reactants A and B in equilibrium with the product C illustrated by:

$$A + B \rightleftharpoons C$$

Using this system for illustrative purposes it is possible to identify examples of the INRC transformation as follows:

1) *Identity (I).* Here the student must appreciate that for a given temperature the equilibrium value, $\frac{[C]}{[A]\ [B]}$, remains constant, i.e., the equilibrium constant is a constant for a specified temperature.

2) *Negation (N).* Here the reduction in the concentration of the reactant A can be negated by increasing the concentration of B.

3) *Reciprocity (R).* Here the effect of either increasing the concentration of A or B or decreasing the concentration of C has a compensating net effect on the position of equilibrium of the system.

4) *Correlativity (C).* Here the negation of a reciprocal transformation (the addition of A by the removal of B) can be achieved by simply increasing B.

The two notions of reversibility (2 and 3 above) are clearly fundamental to the understanding of the equilibrium. It is only when the student comes to the realization that a given net effect on a chemical system at equilibrium can be achieved both through negation and reciprocal transformations that a firm understanding of the phenomenon is achieved. For example, the means by which more product C is produced can be achieved in two ways: by negation of an increased concentration of C (the removal of C), or by a reciprocal transformation, the addition of either or both A or B. Further examples of this nature would support the underlying necessity of the integration of the two forms of reversibility in dealing with the problems of chemical equilibrium.

Many of the items on the Misconception Identification Test (MIT), in addition to their use in identifying major misconceptions in this area, involve particular transformations of the INRC. The attempt to relate individual items to specific transformations revealed that this is a highly complex matter which probably cannot be accomplished by *a priori* logical analysis of the item alone. While empirical data on student reasoning appears necessary, a preliminary categorization was carried out.

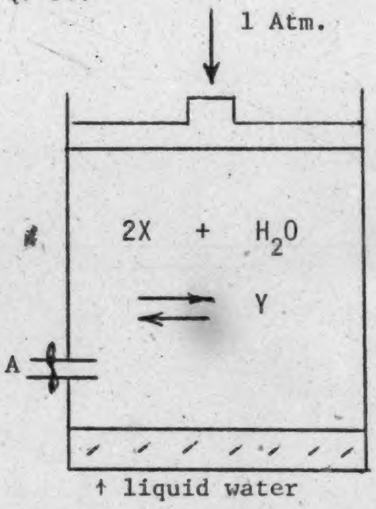
The INRC Group Model and the Misconception Identification Test (MIT)

Table 1 presents the specific transformation corresponding to items on the MIT together with the relevant major misconception.

Representative questions from the MIT illustrating the four transformations follow. All items discussed are taken directly from the complete MIT presented in Appendix A.

1. Identity (I)

Q. 30.



Consider a cylinder (see diagram) containing an equilibrium mixture of X, Y, and H_2O which react according to the equation:

$2X + H_2O \rightleftharpoons Y$, under a constant pressure of one atmosphere. In the cylinder there is gaseous X, Y, and H_2O, together with some liquid water (in which X and Y are quite insoluble).

Water vapor is added to the cylinder through a side valve, A. When the system returns to equilibrium, the number of moles of Y will be ....

Correct answer C

Relevant misconception 5 (Constant concentration)

To correctly answer Q. 30, the student must realize that the operation of adding water vapor to the system, already at equilibrium with excess liquid water, has no effect. That is, the student carries out an identity transformation on the operation (adding water vapor) to correctly predict the effect.

TABLE I

INRC Transformations and Relevant Misconceptions for the MIT

Item	Keyed Answer	Relevant Miscon-ception	INRC Transfor-mation
1	A	2	R
2	B	2	N
3	A	3	I
4	A	1	R
5	A	1	R
6	B	2	R
7	A	1	R
8	A	6	R
9	C	3	I
10	D	4	N/A
11	C	4	I
12	B	6	N
13	B	6	N
14	C	3	I
15	D	4	N/A
16	D	4	N/A
17	A	6	C
18	B	6	C
19	C	3	I
20	B	2	R
21	D	4	N/A
22	B	6	R
23	A	5	C
24	B	1	N
25	A	2	N
26	C	5	I
27	B	5	N
28	A	6	C
29	C	3	I
30	C	5	I

Major misconceptions by number showing number of relevant items on the MIT:

1. Mass vs. Concentration (4)
2. Rate vs. Extent (5)
3. 'Constancy' of Equilibrium Constant (5)
4. Misuse of Le Chatelier's Principle (5)
5. Constant Concentration (4)
6. Competing Equilibria (7)

2. Negation (N)

Q. 27. Some finely divided metallic silver is added to a litre of 0.1M ferric chloride with HCl, and the following equilibrium is set up:

$$Fe^{+3}(aq) + Ag(s) \rightleftharpoons Fe^{+2}(aq) + Ag^{+}(aq).$$

Assume that this is the only equilibrium established.

This equilibrium mixture is diluted to 10 litres with distilled water. When equilibrium is again attained, the number of moles of metallic silver present will be ....

Correct answer B

Relevant misconception 5 (Constant concentration)

In Q. 27 the operation of diluting the system has a negating effect on the number of moles of metallic silver present. That is, the addition of water forces more metallic silver to ionize in order to maintain an equilibrium.

3. Reciprocity (R)

Q. 22. Formic acid, HCOOH, is a weak organic acid and as such partially dissociates in aqueous solution according to the following equation:

$$HCOOH + H_2O \rightleftharpoons H_3O^{+}(aq.) + HCOO^{-}(aq.)$$

To a 0.1M solution of formic acid is added a small amount of concentrated hydrochloric acid which dissociates as follows:

$$HCl + H_2O \rightleftharpoons H_3O^{+}(aq.) + Cl^{-}(aq.)$$

When the system has returned to equilibrium, the molarity of formate ions, $HCOO^-$ will be ....

Correct answer B

Relevant misconception 6 (Competing equilibria)

This question, in contrast to the previous question, illustrates the other form of reversibility, that of reciprocity. Although the net effect of this transformation is the same as that of negation or inversion, it is arrived at by a different route.

In Q. 22, the operation of adding acid results in an increase in the concentration of H_3O^+(aq.) which is compensated by a corresponding decrease in the concentration of the formate ion. Hence to correctly predict that the addition of acid to this system will result in a decreased concentration of formate ion, the student is required to perform a reciprocity transformation.

4. Correlativity (C)

Q. 18. This refers to the following system:

$$CO_{(g)} + Cl_{2(g)} \rightleftarrows COCl_2(g)$$

A certain amount of nitric oxide, NO, is introduced into the system at constant volume and temperature. NO also reacts with Cl_2, according to the following equation:

$$NO_{(g)} + Cl_{2(g)} \rightleftarrows NOCl_{2(g)}$$

When the system returns to equilibrium, the concentration or partial pressure of the $COCl_2$ will be ....

Correct answer B

Relevant misconception 6 (Competing equilibria)

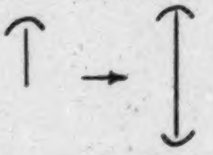
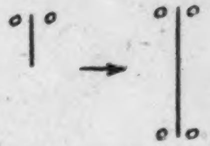
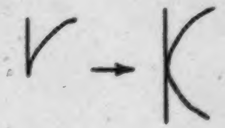
Correlativity is defined as the product of the transformations of negation and reciprocity. In Q. 18 the operation of adding a gas (p) results in the increased concentration of the product in the original reaction (q). That is, there are two distinct and different operations here: p and q. To correctly predict the effect of the operation p on this system the student has first to realize the reciprocal effect on p (this would normally produce an increase in the concentration of the product). However since this is a competing equilibria problem the addition of another gas, nitric oxide, has a negating effect and therefore results in a decrease in concentration of the product, i.e., $C(p)=N(R[p])=q$.

In this manner most of the items on the MIT can be associated with specific transformations of the INRC model. It should be noted that the above examples only serve to illustrate a way of interpreting the four transformations in the area of chemical equilibrium and are not intended to imply that any given transformation is used in isolation. Each operation bears definite relationships to the others. The four transformations form a group in the mathematical sense (Flavell, 1963). This contributes to the difficulties encountered when one attempts to associate a given item to a single transformation. The fact that four of the MIT items presented in Table I (#10, 15, 16 and 21) are not associated with any single transformation of the INRC model attests to the problem.

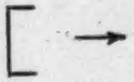
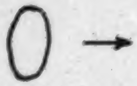
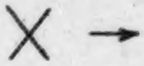
The INRC Group Model and the Skemp Test (SK6)

Items on the Skemp Test (SK6, Part II) correspond to specific transformations of the INRC group. The test is divided into three sections, each illustrating the application of certain cognitive skills.

To illustrate, the first section requires students to perform certain defined operations, in reverse, on certain geometric configurations. An operation F is defined as follows:

Operation F is: add a symmetrical lower half.			

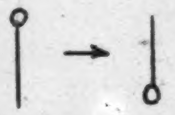
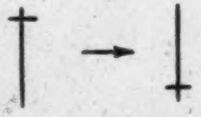
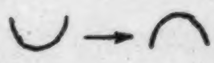
The student is asked to apply operation F, in reverse, to the following configurations:

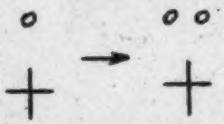
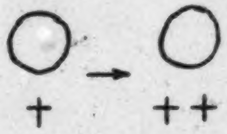
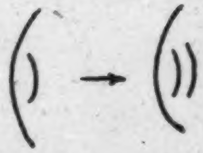
Reverse F.			

Here the effect of reversing the operation F has a compensating or reciprocal effect on the figures. This results in the operation of subtracting a symmetrical lower half.

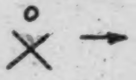
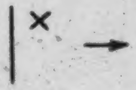
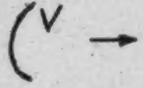
Students operating at the late concrete stage (C_1) should be capable of performing the reversibility operations illustrated by items in this section of the test.

The second section of the Skemp Test deals with the questions involving the combination of two of the previously defined operations on given geometric configurations. For example, two operations are defined as follows:

Operation A is: turn the other way up.			

Operation I is: double the smaller part.			

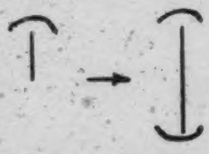
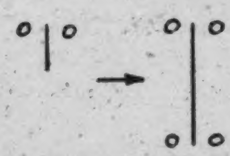
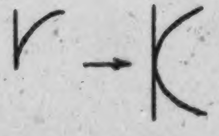
The student then applies both operations A and I, in combination, to the following configuration:

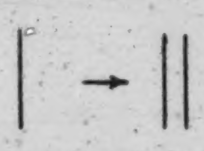
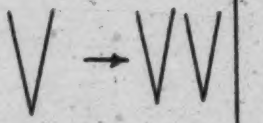
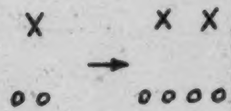
Combine A & I.			

This item requires the student to carry out two operations in combination to produce a net result. As such, questions in this section reflect both a measure of the student's combinatorial ability and his ability to cope adequately with more than one variable at a time. Students at the early formal stage (F_1) should be capable of correctly answering the items in this section.

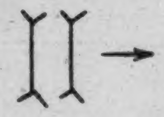
The last section of the SK6 (Part II) requires students to both reverse and combine two operations on prescribed geometric figures. That is, each of these items requires the execution of one form of reversibility (either negation or reciprocity) together with the manipulation of two variables simultaneously. This section of the test is deemed to be indicative of the type of reasoning found at the late formal stage (F_2).

To illustrate, first two operations are defined as follows:

Operation F is: add a symmetrical lower half.			

Operation G is: double everything.			

The student then combines operations F and G, in reverse, to the following configurations:

Reverse and Combine F & G.		((→	88 →

Performance on each section of the Skemp Test together with a total cumulative score will be used as a measure of the student's level of cognitive development. Students having the majority of items correct on all three sections of the test will be considered to be at the highest stage of development (F_2). That is those students who are capable of answering the third section of the test correctly in addition to correctly answering the two earlier sections, are considered to be operating at the F_2 level. This is because the third section requires the students to perform "operations on operations," a basic characteristic of formal operational thought. Students answering the majority of items on the first section accurately will be considered to be at the stage of early concrete thought (C_1). Students answering the majority of items correctly on the first two sections but not the last section will be considered to be at the late concrete stage (C_2) or early formal stage (F_1). The student's capacity to use the integrated INRC group structure is most closely associated with the last section of the test.

Both the Skemp Test (SK6) and the Piagetian Tasks (PT 1 and PT 2) are used as measures of the students' perception of the INRC group model. Performance on these instruments serves as the basis for the classification of the students into the stages and substages of concrete and formal thought.

Studies of Chemical Equilibrium

The concept of 'equilibrium' has wide currency throughout the physical and social sciences as a way of characterising system states. Flavell (1963) notes that the global conception of the 'equilibrium model' in the psychological sense had, as its origin, Piaget's early involvement in the field of biology. The classical studies involving equilibrium in the mechanical sense, namely those of equilibrium in the hydraulic press and equilibrium in the balance, are fully described in Inhelder and Piaget (1958, Part II). These experiments are designed to explore the scientific thinking of the adolescent and are unique in their purpose and wide significance in that it is claimed that the thought processes revealed in these science experiments will also be revealed in other fields of human activity.

Equilibrium in the dynamic 'chemical sense' has received far less attention than models of mechanical equilibrium in science education in relation to psychological theory. A review of the major studies and their relevance to the present study is now considered.

D. R. Driscoll (1966), in his study of the reasoning involved in the solving of chemical equilibrium problems in high school chemistry, identified several major misconceptions or incorrect modes of thinking possessed by students in that area. In order to pinpoint some of the misconceptions in this area a test of chemical equilibrium involving multiple choice items was given in 1966 to some 500 first year science and medicine students at the University of Melbourne immediately prior to the start of the academic year. Virtually all of these students had passed their examination in Matriculation chemistry three months earlier.

Items on the test of chemical equilibrium were designed in such a way that students were required to predict the effect of changing certain factors (i.e., temperature, pressure, concentration) on a chemical system at equilibrium. Items were primarily of the four option multiple choice variety similar to those in the MIT. A selected sample of students were asked to give free-response accounts of their reasoning for particular questions. Inferences about how they reasoned were drawn from their choice of answers and, in particular, from the pattern of their responses which dealt with similar misconceptions. This served to validate an interpretation of a particular answer or 'pattern' of answers.

For example, if a student answered a question incorrectly, this does not in itself mean too much. However if he answered several questions incorrectly which all measured the same concept, one could be reasonably sure that the student was having trouble with the particular point. The above approach, coupled with the student's free-response accounts of just how he had reasoned towards a particular answer, served as the basis for misconception identification.

As discussed earlier, the interpretation of multiple choice type diagnostic items is not an easy task. A student can arrive at the correct answer either by guessing or by making a 'wrong' mistake (so to speak) or by otherwise arguing incorrectly. He may also arrive at a particular incorrect answer by a variety of incorrect pathways. Driscoll's decision to interpret his results using both patterns of answers to a number of related items and the consideration of free-response accounts for the reasoning involved for given questions represents an effort to overcome these inherent difficulties. The inclusion of the reasoning section with items sampled on a random basis in the Misconception Identification Test (MIT) of the present study represents a modified approach to the problem. In this section of the MIT, each student is asked to state his or her reasoning followed in choosing his or her responses for five randomly chosen items. In addition the student is asked to indicate which law or principle was used in arriving at each item response.

The results of Driscoll's analysis suggested the presence of the following misconceptions and faulty approaches in his sample:

(1) Uncertainties about the quantitative and/or qualitative significance of the equilibrium law. These included the inability to perceive the algebraic/arithmetical implications of the equilibrium law, the failure to consider all those factors which can produce a change in the equilibrium condition and the uncertainty surrounding certain concepts involved in equilibrium.

(2) An excessive tendency to use what he called "Le Chatelier-type" reasoning, that is, reasoning which is qualitative in situations requiring a quantitative approach.

(3) A predisposition to apply equilibrium relations to other than equilibrium considerations. In particular Driscoll found a tendency in his subjects to confuse rate of reaction with the extent of a reaction.

Driscoll also suggested some techniques and methods which he felt would be useful to the chemistry teacher in order to minimize or eliminate certain misconceptions. For example, he found that the confusion associated with the constancy of the equilibrium constant is largely eliminated when one introduces a graphical approach to teaching certain areas of equilibrium. The clarification made by combining various curves (e.g., concentration vs. time, reaction quotient vs. time, number of moles vs. time, etc.) in his teaching of equilibrium was noticeable.

An important need seen by Driscoll was for a more quantitative approach to chemical equilibrium in certain areas where intuitive or 'Le Chatelier type' reasoning proves inadequate. The limitations of this qualitative approach in solving chemical equilibrium problems should be clearly conveyed to the student (Driscoll, 1960). Driscoll found a high correlation ($r = .90$) between student performance on equilibrium questions involving gases and comparable questions involving solutions. This may well reflect a need for a firm understanding of chemical equilibrium in a specific area (i.e., homogeneous gaseous reactions) before the students confront other forms of equilibria. Perhaps the present CHEM Study approach to the whole unit on chemical equilibrium, which tends to deal with the two areas simultaneously, will have to be examined more closely in the light of this evidence.

Although Driscoll's work was conducted in an Australian school setting, his findings strongly influenced the approach taken in the construction of the Misconception Identification Test (MIT) used in the present study. The nature of the data by which the misconceptions are classified according to the earlier defined types (I, II, or III) closely parallels Driscoll's method of obtaining free response accounts to certain questions. Further, the six major misconceptions involved in the MIT incorporate the three general misconceptions found by Driscoll. Obvious modifications to suit both terminology and content of the CHEM Study course were deemed necessary for the present study.

Several studies in chemistry reflecting Gagné's cumulative learning model have been conducted (Kolb, 1967; Airasian, 1970;

Nicodemus, 1970; Okey and Gagné, 1970; Capie and Jones, 1971). In this model Gagné proposes that the attainment of subject matter competence is hierarchically organized, and the normal analysis procedure used to determine intellectual skills is called 'deriving a learning hierarchy' or task analysis.

In task analysis, one begins with a clear statement of some terminal objective of instruction. This final capability is then analyzed into a hierarchical sequence of subordinate skills by successively asking the question of each task, "What should the individual already have to be able to do in order to learn this new capability simply by noting verbal instructions?" The resulting hierarchy is then empirically tested and revised until students can in fact achieve the terminal objective through instruction following the hierarchy.

The validity of a given learning hierarchy can be established from an analysis of the results of the administration of a test especially constructed to yield pass-fail information on each entity within a total hierarchy (Gagné, 1967). A necessary but not sufficient condition for establishing the validity of a learning hierarchy is that a larger percent of the sample of students tested must be successful on objective 1 than on objective 2, than on objective 2 than on objective 3, and so on up the hierarchical ladder. To conclusively validate the hierarchy, data on each individual rather than group data would have to be obtained. If the cumulative learning model is accurate, then any inability to perform a task should be attributable to failure on skills subordinate to it (Harke, 1971). A detailed assessment of the techniques used in hierarchy validation has been carried out by Capie and Jones (1971).

A limitation of task analysis is that it is initially carried out almost exclusively in the mind of the adult, and, in general, children's logic is unlike adult logic. Nevertheless, a Gagné type task analysis used in conjunction with Piaget's developmental sequence could prove profitable in curriculum development. For example, in connection with the misconceptions in chemical equilibrium under investigation in the present study, task analysis might lead to a workable instructional sequence designed to alleviate certain misconceptions. However, one must be careful to distinguish between "facts" which are to be learned and "logical operations" which must be developed.

Okey and Gagné (1970) have developed a learning hierarchy for solving solubility product problems, involving some fifteen subordinate or prequisite skills. A group of 135 tenth, eleventh and twelfth grade students from five chemistry classes studied an initial version of a learning program followed by tests on the criterion task (ability to solve solubility problems) and on selected subordinate skills deemed necessary. The program was revised by adding additional instruction on those subordinate skills failed by many students. A second student group studied the revised program and took the same tests. Four different tests were used to measure student performance: a pre- and posttest on the criterion task, and a pre- and posttest on the subordinate skills in the learning hierarchy. The results showed that adding instruction leading to improved performance on subordinate skills was successful in significantly improving performance on the criterion task. In the hierarchy eleven of the fifteen subordinate skills deemed necessary to the criterion task were mathematical in nature.

Although this type of study has several built-in diagnostic features, one wonders whether an over emphasis is not placed upon the mathematical prerequisite skills. It may well be that mathematical ability is a necessary condition for the understanding of certain types of chemical equilibrium but surely it is not a sufficient condition.

Studies conducted by Pella and Triezenberg (1969) and Ring and Novak (1971) reflect an emphasis on Ausubel's theory of meaningful learning. Ausubel's subsumption model suggests that central unifying ideas of a discipline be taught first and that less inclusive ideas be related clearly and logically to the unifying ideas by subsumption. Central unifying ideas or conceptual schemes thus become advance 'organizers.'

Ausubel's model assumes the existence of a cognitive structure that is hierarchically organized in terms of highly inclusive, conceptual traces under which are subsumed traces* of less inclusive subconcepts. The major organizational principle, in other words, is that of progressive differentiation of trace systems of a given sphere of knowledge from regions of lesser to greater inclusiveness, each linked to the next higher step in the hierarchy through a process of subsumption.

The task of identifying those particular organizing and explanatory principles in the various disciplines which manifest the widest generality and integrative properties is obviously a formidable and long-range problem. These should be capable of being derived from what Bruner (1961) has called the structure of the subject. Ausubel

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*The term trace is used as a hypothetical construct to account for the continuing representation of past experience in the nervous system and in present cognitive structure.

(1963) maintains that sequential organization of subject matter, combined with the use of appropriate advance organizers, can be very effective in classroom learning because each new increment of knowledge serves as an anchoring post for subsequent learning. The basic paradigm of sequential organization is not from easy to difficult, but from general to specific.

Thus, if one is introducing equilibrium in a chemistry course for the first time, a relevant organizer might be of equilibrium in various types of balances drawn from past experiences of the child. However, an interesting paradox arises: where and how does one first acquire the rudimentary concepts necessary to construct the first organizers for the child? Piaget has given us a vast array of interesting data and extremely useful observations, all of which imply orderly development in cognitive functioning given adequate experiential backgrounds. Adequate development not only indicates the integration of relevant concepts within a discipline, but being aware of the similarities and differences between disciplines. Piaget's observations regarding the cognitive growth of children have delineated sequences in the developmental process with at least two important dimensions: 1) subjective-objective and 2) concrete-abstract.

The study conducted by Pella and Triezenberg (1969) investigated three types of presentation of the conceptual scheme of equilibrium in the teaching of ecology using the subsumption model. The relative effectiveness of three levels of abstraction (verbal, pictorial and working model) in the presentation of the advance organizer, equilibrium, was conducted with 270 pupils in Grades 7, 8 and 9. Effectiveness of the three levels of stimuli was tested by comparing the results achieved by three treatment groups. Treatment 1: The conceptual scheme of equilibrium was presented verbally. Treatment 2: Equilibrium was presented verbally supplemented by sketches of appropriate models. Treatment 3: The conceptual scheme of equilibrium was presented verbally supplemented by appropriate mechanical models. The three aspects of equilibrium utilized in each treatment were, in order of presentation: 1) static equilibrium as exemplified with a beam balance, 2) dynamic equilibrium as found in a closed system involving evaporation and condensation, and 3) adjustment within a closed system that is thermostatically regulated. Testing involved multiple choice objective pre- and posttests on the concepts found in the three aspects of equilibrium. Results of the study indicated that the use of working models for reference to the "organizer" is superior to verbal reference or the use of sketches.

Ring and Novak (1971) investigated the relative influence of facts and subsuming concepts on facilitation of new learning in college chemistry. The sample consisted of 770 students taking their first course in college chemistry at Cornell University. The subjects were tested to ascertain their cognitive structure previous to any college instruction in chemistry. The function of this examination was to describe the fact and subsumer orientation of each subject's cognitive structure. An objective Cognitive Structure Exam (C.S. Exam) was developed by the investigators. The criteria used in selecting items were relevance to high school chemistry, the subsumer, or the factual nature of the item, and relevance to college chemistry. The results of the study supported the thesis that the amount of relevant subsumers within cognitive structure facilitated the learning of new material. This type of study is representative of those employing the 'subsumption' model which indicates that a minimum of relevant concepts significantly enhance achievement.

The present study recognizes that the amount of factual information possessed by a learner may be positively related to the amount of new material he is able to assimilate. However, little account is taken in the studies reviewed using Ausubel's model of the developmental level of the students. It may well be that a certain level of abstraction, as in the case of the Pella and Triezenberg study, is more successful with students operating at the level of concrete operations than at the formal operational stage.

The studies of Kolb (1967), Case (1970), and Dence (1970) deal with the relationship between mathematical ability and achievement in chemistry. Kolb dealt with the effect that an instructional sequence in high school mathematics, directly related to selected quantitative science behaviors, has on the acquisition of the quantitative science behaviors. His results indicate that the effect is a favorable one and would support the work of Dence in his study on the mathematical competence required for freshman college chemistry (Dence, 1970).

The purpose of the study carried out by Case (1970) was to determine the characteristics of secondary school chemistry students who were successful in grasping a mathematical approach to teaching chemical equilibrium. The sample for the study consisted of 89 senior high school students who had completed a first year algebra and plane geometry course. An experimental mathematically based unit on chemical equilibrium was developed for use with secondary school students. Students devoted the same amount of time to the experimental unit as had been allocated for the 'regular' representation of chemical equilibrium. The experimental unit consisted of six individual daily lessons, six individual tests over each lesson, and a final test over the entire unit. Case found that a mathematical approach to teaching chemical equilibrium is not beyond the ability of the secondary school student but, in order for the topic to be most meaningful, it should be reserved for essentially the top twenty percent of the student population.

One of the suggestions offered by Driscoll (1966) in his investigation concerning misconceptions in chemical equilibrium was for a more quantitative approach to the teaching of certain types of equilibrium problems. This arose from the finding that students had an excessive disposition to apply intuitive reasoning to many problems on chemical equilibrium that required a more quantitative or empirical approach. The present study will attempt to ascertain the relationship (if any) that student mathematical ability has with the number and nature of misconceptions in chemical equilibrium and achievement in chemistry. It may be that an inability to apply basic mathematical skills in chemistry accounts for certain misconceptions in this area.

The only Piagetian based study found dealing with chemical equilibrium specifically has been conducted by Buell and Bradley (1972). The study involved the application to a binary system (temperature of solvent vs. weight of solute per 100 gm. water, using aqueous solutions) of Piaget's 16 binary propositional operations and was conducted with 70 high school chemistry students. Initially each student was given an Introductory Phase packet consisting of: 1) a graph of the solubilities of five salts over a temperature range, and 2) a brief statement of what the graph was concerned with and the request "write down your interpretations of the relationships which exist on the graph and, if possible, indicate how you arrived at your conclusions." The purpose in the Introductory Phase was to ascertain at what Piagetian stage the students were, although detailed description as to the criteria used to place the students into their respective developmental stages and substages is not given.

A Directed Question Phase packet was administered after two weeks of laboratory work and discussion of solubility/temperature relations at equilibrium, to determine how many of the students were at which stage and substage of development. The Directed Question Phase packet consisted of 1) the same graphs but with a separate table of solubilities, and 2) a series of questions concerning various concepts illustrated by the graphs.

Results of the study were somewhat discouraging. Following the two week laboratory treatment on solubility equilibria, the posttest results showed a decrease in the percentage of students attaining the logical operational stage, F_2. Eighteen percent were thought to be at the stage of logical operations while on the Directed Question packet no one was considered at the logical operational stage. Most students (91%) were found to be at the early formal stage, F_1, while only 9% were at the concrete operational stage. It was therefore suggested that laboratory contact with the realia of solubility does not improve logical thinking about constants and variables. Buell and Bradley (1972) conclude by stressing a greater need for the teaching of logical thinking, in addition to manipulation of chemical glassware.

The present study attempts to relate misconceptions in chemical equilibrium using another aspect of Piaget's theory (the INRC group model) in contrast to the 16 binary operations model. Performance on certain Piagetian tasks (PT 1 and PT 2) used in the present study was measured according to specific criteria based on Piaget's own experimentation. Unlike the study reviewed above no attempt is made to measure any change in the developmental stage or substage for students as a result of some treatment. The purpose is, rather, to determine if the extent to which students use the INRC group model is associated with misconceptions in chemical equilibrium.

The studies reviewed above suggest that the understanding of chemical equilibrium is a complex problem involving several factors which need to be studied both from a psychological and methodological basis. It has been shown by Driscoll (1966) that student misconceptions do exist in chemical equilibrium. These may be related to the cognition level, mathematical ability, approach taken and specific content studied. The fact that most of the studies reviewed are fairly recent is an encouraging sign and indicates an ever increasing concern for the teaching of one of the most important principles in chemistry.

A brief review of related research on misconceptions in science is now considered.

Misconception Studies in Science

Misconceptions can be assessed via an objective test (i.e., multiple choice by observing the number of students choosing the various options which represent errors or misconceptions). This kind of analysis was done by Merrill (1970) on some of the National Assessment of Educational Progress (NAEP) science data with the NAEP science testing program. As with most tests, the options for each item were not designed according to any underlying misconception scheme. Therefore only statements related to specific misconceptions on isolated items could be made.

The work of Driscoll (1966) reviewed earlier also involved a multiple choice test using item response pattern. Free response reasoning for the items was also obtained to further strengthen the interpretation given to his results. In spite of certain inherent dangers always present in a multiple choice situation this approach appears to have some validity for the determination of student misconceptions in science.

While a number of research efforts (Atwood, 1968; Gilman et al., 1960; Merrill, 1970) have been completed which assess student's misconceptions concerning science concepts, the studies vary widely in their techniques and grade level and no clear-cut guideline or procedures have yet been established. Furthermore, no one misconception scheme has been widely accepted to date, although many have been suggested.

Gilman, Hernandes, and Cripe (1970) used the following system: correct response, common misunderstanding of the concept, and two other reasonable and plausible distractors. In a study related to classificatory behavior, Tennyson, Wooley and Merrill (1971) described possible errors as over-generalization, under-generalization and misconception. The present approach involved asking the respondent to make a prediction based on information given.

Summary

Piaget's theory of cognitive development was outlined here with special emphasis on the formal operational stage. The physical INRC group model was presented and discussed with reference to chemical equilibrium. Particular attention was given to the criteria used for evaluating performance on the Piagetian Tasks (PT 1 and PT 2) and the Skemp Test (SK6, Part II) in relation to the INRC model.

Relevant science education research based on Piaget's theory was presented together with studies on chemical equilibrium. Problems associated with this area were discussed in relation to the present investigation.

CHAPTER III

EXPERIMENTAL DESIGN

The Sample

The sample for this study was drawn from the population of Edmonton high schools on a semester system using the CHEM Study text book in a conventional classroom. Five senior high schools, three from the Edmonton Public School System and two from the Edmonton Separate School System, were selected at random from the above population. The investigator approached the Director of Educational Research at the Edmonton Public School Board and Research Consultant of the Edmonton Separate School Board for their permission to conduct the study. This was done through the Division of Field Experiences of the Faculty of Education, University of Alberta. After receiving permission to conduct the study from the above mentioned individuals, the investigator approached the Science Coordinators of the above schools through the respective principals to request participation of their students in the study. Although the principals and Chemistry 30X teachers in all schools contacted consented to participate in the study, two schools had to be dropped from the study due to timetabling problems.

One of the schools was selected to participate in the pilot study. The pilot study involved three out of the total of eight Chemistry 30X classes in that school and a total of 62 students. All of the students in the three classes in the pilot study were taught by the same teacher.

The main study was conducted with five Chemistry 30X classes in two high schools, one in each of the Edmonton Public and Separate school systems. The final sample for the main study consisted of 99 students. Of the three teachers involved in the main study, two taught two classes each and one of the teachers taught one class.

Since some students were absent on any of the four days that testing was carried out, there were a number of students for whom complete data sets were not available. These students were dropped from the sample. Of the total of 125 students in the five Chemistry 30X classes in the main study a total of 26 students were dropped from the sample because of incomplete data.

The students were tested on four separate days over a period of three weeks during the months of April and May of the spring semester 1973. A more complete description of the procedure used in testing follows the discussion of the tests.

The Tests

The following section describes the test instruments used in the study and outlines their development. The statistical results obtained from these tests are discussed in Chapter IV.

The Misconception Identification Test (MIT)

The purpose of the Misconception Identification Test (MIT) was to provide a measure of both the nature of student misconceptions in chemical equilibrium and the degree to which they occur. The MIT is a 30 item, four-option, open book examination of 60 minute duration which was devised for this study. Items on the MIT deal with examples of chemical equilibrium with regard to homogeneous gas reactions, phase changes and aqueous solutions of ionic solids.

The MIT requires students to predict the effect of various variables on the equilibrium conditions of several chemical systems and state the principle or law used in their reasoning. The means by which the misconceptions are classified into the previously defined types is also provided by the reasoning section of the MIT. That is, a Type I misconception is said to occur when the item response is correct but the stated reasoning is incorrect. Type II misconceptions occur when the response is incorrect and the reasoning given is correct, that is, the stated reason is either too limited or incomplete. Type III misconceptions occur when both the response and reasoning given are incorrect.

Items on the MIT were deemed representative of difficulty of the Chemistry 30X course in terms of content and degree by a number of consultants.

The investigator prepared a first draft of the MIT consisting of 35 4-option multiple choice questions. The work of D. R. Driscoll at the Canberra College of Advanced Education, Australia, largely influenced the initial form and approach used in constructing this version of the MIT. Written permission to use portions of Driscoll's test on Chemical Equilibrium was obtained. The test was then given to three experienced Chemistry 30 teachers whose classes were not involved in the present study together with two University instructors in science for their criticism. This resulted in five items being dropped from the test for reasons of relevance and difficulty. In addition it was suggested by the consulting group that the instrument was too long for the intended 60 minute time period. This resulted in the decision to randomly sample the student reasoning section of the MIT rather than to require each student to specify his reasoning for each of the 30 items on the test.

By this technique an indication of the reasoning used could be obtained for all items, although any given student was only required to specify his reasoning for a few randomly chosen items. To accomplish this, six versions of the reasoning section, each sampling five different items on the MIT, were constructed.

Having incorporated the suggested changes deemed necessary by the consultants, the revised MIT was then administered as a closed book test to the three Chemistry 30X classes in the pilot study. The 30 test items together with the section requiring the students to state their reasoning for specific questions was found to be a suitable length for completion in the 60 minutes allowed for the instrument. Two teachers who examined this form of the MIT felt it was rather a difficult test. However it was felt to have a high degree of content validity relative to the chemical equilibrium material in the CHEM Study course. It was agreed that the MIT should be made an open-book examination.

The MIT was again revised on the basis of an item analysis carried out on the 62 students in the pilot study together with teacher criticisms. In an effort to increase the difficulty index of several items (those with difficulty index of less than 0.20), terminology more consistent with the CHEM Study approach to equilibrium was included in those items. Several minor changes in format were also made, including the addition of a small section which asked students to specify which law or principle was used to arrive at their response for certain items.

As stated earlier the MIT was designed to measure the nature of student misconceptions in chemical equilibrium and the degree to which they occur. Six major misconceptions were identified for use in the study. A discussion of each misconception, illustrated by an item from the MIT used to detect the misconceptions, follows.

Misconception 1. *Mass-concentration*

This misconception is concerned with the confusion between the terms mass and concentration and the relationship between them. Students who associate increased concentration with an increase in mass and vice versa as illustrated by given items on the MIT are considered to possess a mass-concentration misconception.

To illustrate this misconception with specific items, consider the gaseous equilibrium mixture of CO, Cl_2, and $COCl_2$ initially at 200°C and 1 atmosphere pressure, the original reaction used in items 1 to 20 on the MIT.

The balanced equation is given by:

$$CO\,(g) + Cl_2(g) \rightleftharpoons COCl_2(g),$$

the forward reaction being exothermic (i.e., taking place with the evolution of heat).

Questions 1-20 were answered by choosing the most appropriate of the following responses:

A. *Greater than* at the first equilibrium.

B. *Less than* at the first equilibrium.

C. *The same as* that at the first equilibrium.

D. *There is insufficient evidence* provided to decide among the above alternatives.

Questions 5 and 7 are associated with the mass-concentration misconception and refer to the following change made on the original reaction: The volume of the system is halved by increasing the pressure at constant temperature. When the system has returned to equilibrium:

Q.5. the concentration (or partial pressure) of $COCl_2$ present will be

....

Correct answer A.

Q.7. the concentration or partial pressure of CO present will be

....

Correct answer A.

These questions illustrate examples of two important situations: one in which the mass or number of moles of the substance increases as does the concentration of that substance (as in Q.5) and one in which the mass of a substance decreases as the concentration increases (as in Q.7) because of a volume change. Students who incorrectly answer Q.5 and Q.7 fail to appreciate that an increased mass does not necessarily imply an increased concentration (or vice versa) and therefore are said to possess a mass-concentration misconception or misconception 1. Other questions on the MIT that are associated with misconception 1 are questions 4 and 24.

Misconception 2. *Rate-extent of reaction*

Misconception 2 refers to the confusion between the rate of a reaction and the extent of a reaction. That is, the uncertainties between the velocity (rate) at which a reaction is proceeding and the position of equilibrium (extent) which is attained. Although both concepts are determined by an energy consideration it is vitally important for the student to clearly differentiate between them in chemical equilibrium. Students were considered to possess a 'rate-extent misconception' if they contended that increasing the rate of a chemical reaction alters the position of equilibrium (or vice versa).

To illustrate misconception 2 consider questions 1 and 2 on the MIT referring again to the original reaction:

$$CO(g) + Cl_2(g) \rightleftharpoons COCl_2(g) + \text{heat.}$$

The following change is made on the above reaction:

The mixture is cooled to 150°C (at which temperature all three substances are still completely in the gaseous state), keeping the volume constant. Questions 1 and 2 concern the system after equilibrium is again attained and are as follows:

Q.1. the number of moles of $COCl_2$ present will be ....

Correct answer A.

Q.2. the rate at which $COCl_2$ is being formed will be ....

Correct answer B.

Students who predict that the mass of $COCl_2$ formed in Q.1 will increase but fail to realize that the rate of reaction in fact decreases will be considered to possess the misconception termed rate-extent of reaction. Similarly students who predict that the decreased rate of reaction will therefore produce less mass of $COCl_2$ fail to realize the significance of both the rate and the extent of a chemical reaction.

Questions 6, 20, and 25 on the MIT are also associated with misconception 2.

Misconception 3. *Constancy of Equilibrium Constant*

By misconception 3 is meant the inability to realize when the equilibrium constant is or is not in fact a constant. Those students who fail to predict a change in the numerical value of the equilibrium constant because of a temperature change are said to possess misconception 3. Similarly students who predict a change in the value of the constant when the temperature is held constant also hold the misconception of the constancy of the equilibrium constant.

Question 9, dealing with the original reaction as explained under misconceptions 2 and 3 above, serves to illustrate misconception 3. Here some Cl_2 is removed from the system, the volume and temperature being held constant. When the system has returned to equilibrium:

Q.9. the equilibrium value of $\frac{[COCl_2]}{[CO] \quad [Cl_2]}$ will be ....

Correct answer C.

In question 9, although the concentrations of both the product $COCl_2$ and the reactants CO and Cl_2 do change, the numerical value of the above expression, the equilibrium constant, remains unchanged. Those students who incorrectly predict a change in the value of the constant and thereby answer the question incorrectly are said to possess misconception 3.

Four other questions on the MIT are relevant to misconception 3, namely questions 3, 14, 19, and 29. Only one question, number 3, involves a change in the numerical value of the equilibrium constant because of a change in temperature. In all other questions the temperature of the given reaction is held constant and hence the value of the equilibrium constant is maintained. Students who fail to appreciate that the value of the constant is dependent on the temperature only are considered to possess misconception 3.

Misconception 4. *Misuse of Le Chatelier's Principle*

The misuse of Le Chatelier's Principle misconception refers to situations where students, failing to fully realize the limitations of this principle, apply it to inappropriate situations. The application of Le Chatelier's Principle to chemical equilibrium problems which require a quantitative, empirical approach is considered a misuse of this principle. The point to be made here is not a criticism of Le Chatelier's Principle (every principle has its limitations) but that students fail to realize its limitations. This intuitive application of Le Chatelier type reasoning to equilibrium problems not amenable to this approach is the basis for identifying misconception 4.

Consider questions 15 and 16 on the MIT that refer to the original reaction as follows:

Q.15. One mole of $COCl_2$ and 0.01 mole of Cl_2 is added at constant volume and temperature. When the system has returned to equilibrium, the number of moles of CO will be ....

Correct answer D.

Q.16. this time, 0.01 mole of $COCl_2$ and 1 mole of Cl_2 is added at constant volume and temperature. When the system has returned to equilibrium the number of moles of CO will be ....

Correct answer D.

In both Q.15 and Q.16 there is insufficient information given to correctly predict the change produced. A quantitative solution based on initial equilibrium concentrations for the reactions would be required to answer these questions. Students who incorrectly respond to these questions by answering A, B, or C are said to possess misconception 4.

Questions 10, 11, and 21 on the MIT are also associated with a 'misuse of Le Chatelier's Principle'.

Misconception 5. *Constant concentration*

Misconception 5 arises when students fail to appreciate that certain substances possess a fixed or constant concentration in chemical reactions. The equilibrium established is therefore independent of the actual mass of a substance with constant concentration. This misconception is seen to arise mainly in chemical problems dealing with ionic solutions in equilibrium with an excess solid. In this instance the excess solid is said to have a constant concentration and removal or addition of solid will not affect the established equilibrium (assuming constant temperature).

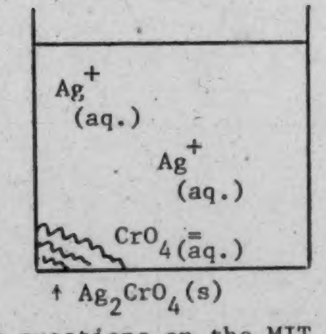
Consider question 26 on the MIT as follows:

Q.26. A vessel contains an aqueous solution of Ag^+ (aq.) + $CrO_{4(aq.)}^{-2}$ ions in equilibrium with solid Ag_2CrO_4.

$$2Ag^+(aq.) + CrO_{4(aq.)}^{-2} \rightleftharpoons Ag_2CrO_4\ (s).$$

Half of the solid Ag_2CrO_4 present is now removed. Analysis of the solution after many hours would indicate that the molarity of Ag^+ (aq.) is now ....

Correct answer C



Those students who will incorrectly predict a change in the silver ion concentration, either an increase or a decrease, are said to possess misconception 5.

Other questions on the MIT that are relevant to misconception 5 are Q. 23, 27, and 30.

Misconception 6. *Competing equilibria*

Misconception 6 occurs when students fail to consider all possible factors that may affect the equilibrium condition of a chemical system. This inability to appreciate that several factors may alter an established equilibrium is best illustrated by questions on the MIT in which two reactions are competing for equilibrium. In question 17, both nitric oxide and carbon monoxide react with chlorine to form respective products as follows:

$$NO(g) + Cl_2(g) \rightleftharpoons NOCl_2(g)$$

$$CO(g) + Cl_2(g) \rightleftharpoons COCl_2(g)$$

Question 17 asks the student to predict the effect on the number of moles of CO as a consequence of introducing a small amount of nitric oxide, NO, into the system at constant volume and temperature.

Correct answer A.

Unless the student realizes that the introduction of the nitric oxide affects the original equilibrium of the CO system by depletion of chlorine gas, he will be unable to correctly predict the effect on the original system.

Other questions on the MIT that are associated with misconception 6 are Q. 8, 12, 13, 18, 22, and 28.

Each item on the MIT was designed to detect the presence of one of the above six misconceptions. Table I (p. 39) presents the complete breakdown of the MIT items and their relevant misconceptions together with the total number of items written for each major misconception. The six misconceptions as reflected in the MIT are those which are deemed critical to a firm understanding of chemical equilibrium at the high school level, and are not necessarily exhaustive of the set of possible misconceptions. They are based on personal perceptions by the investigator while teaching chemical equilibrium and in consultation with experienced people in the field.

In addition to their use of identifying the major misconceptions in chemical equilibrium, many of the MIT items also correspond to one of the four transformations of the INRC group model. The specific transformations corresponding to items on the MIT are also shown in Table I.

Item analysis of the MIT on the basis of the 62 students in the pilot study confirmed the difficult nature of the test. Of the 30 items on the MIT, eight had an item difficulty of less than 0.30. The average item difficulty index of the MIT was 0.41.

The reliability of the pilot version of the MIT, as calculated by the Kuder-Richardson formula 20, was found to be low. The KR-20 reliability coefficient is a measure of the internal consistency, or homogeneity, of the test. As the questions on the MIT measure several different attributes dealing with various types of equilibria, the internal consistency coefficient would be expected to be low (Ferguson, 1971, p. 368). When the MIT was keyed according to the misconceptions that students were expected to possess, the reliability (KR-20) was seen to increase markedly (from 0.15 to 0.49). This was taken as evidence for the consistency of the MIT in detecting student misconceptions in this area. Given the high difficulty of most items and the nature of the KR-20 formula, the reliability coefficient as calculated was not considered unrealistic.

A more complete discussion of the MIT test statistics is presented in Chapter IV. The revised MIT is presented in Appendix A. A summary of the MIT statistics is presented in Appendix E.

The Chemistry Achievement Test (CHAT)

The purpose of the Chemistry Achievement Test (CHAT) was to provide a measure of students' achievement in the area of chemistry involved in the present study. The CHAT is based on Chapters 7, 8, 9, and 10 of the CHEM Study text. These chapters are entitled, respectively: "Energy Effects in Chemical Reactions," "The Rates of Chemical Reactions," "Equilibrium in Chemical Reactions," and "Solubility Equilibria." As such the CHAT covers a substantial portion of the present Chemistry 30X course and involves items which measure understanding of chemical equilibria and related concepts.

The CHAT was originally devised by Lantz (1972) for use in his study of the students' perception of the Kinetic Molecular Theory (KMT) as related to achievement in high school chemistry. The CHAT is a 33 item five-option, multiple choice open book examination of 60 minute duration.

The reliability as reported by Lantz in his study (p. 43) using the Kuder-Richardson 20 formula was 0.71 for the 275 students who wrote the test and 0.71 for the 198 students in his final sample. For the 62 students in the preliminary study associated with the present investigation, the reliability was found to be 0.76. The reliability was 0.75 for the students in the final sample.

The CHAT is presented in Appendix B and a summary of its test statistics is given in Appendix E.

The Skemp Test (SK6)

The SK6 (Part II) test was devised by Dr. R. R. Skemp, Lecturer in Psychology, Manchester University, England. Written permission to use the SK6 (Part II) test was secured from Dr. Skemp beforehand with the understanding that it would be used only for the investigator's personal research.

The SK6 (Part II) consists of 45 test items involving the manipulation of certain geometric configurations based on ten clearly defined operations. These items involve transformations of reversibility, both negation and reciprocity, and combination as well as items requiring various types of combinations of transformations. The test is divided into three sections, each consisting of 15 test items. The first section, SK6(1), deals with operations involving reversibility while the second section, SK6(2), deals with operations involving two operations in combination. The third section, SK6(3), consists of items which require students to combine operations in reverse.

As the items on the SK6, Part II, involve examples of the INRC group, performance on the test was used as a measure of the students' ability to use the INRC model. A more detailed description of the SK6 items and their relationship to the Piagetian transformations is presented in Chapter II.

In addition to a total score for the test, separate scores for the SK6 (Part II) were obtained for the three types of items, i.e., reversibility, combination, and combination of reversing and combining. As proper administration is critical to the use of the Skemp Test, it was administered to the three Chemistry 30X classes in the pilot study to insure that the investigator was familiar with the administration of the instrument.

The SK6 (Part II) is presented in Appendix C and a summary of its test statistics is given in Appendix E.

The Combination of Colorless Chemical Bodies Tests (PT 1 and PT 2)

The purpose of the Combination of Colorless Chemical Bodies Tests (PT 1 and PT 2) was to provide a measure of the present level of cognitive development of the students. For the purpose of this study these tests have been labelled Piagetian Tasks I and II (PT 1 and PT 2). PT 1 is based on the classical experiment conducted by Inhelder and Piaget (1958) and fully described on p. 107-122 of *The Growth of Logical Thinking*. PT 1 involves combinational operations in their general form and includes notions relative to inversion and reciprocity. In the problem of the colorless solutions five similar beakers containing colorless, odorless liquids, numbered 1, 2, 3, 4, and 'a' are presented to the student. Two beakers are then shown to the students, one containing solutions 1 and 3 and the other only solution 2. While the students watch, the experimenter adds several drops of 'a' to each of these beakers. The solution in the beaker containing 1 and 3 turns yellow while no change is noted in the beaker containing solution 2. On this basis the students are asked to reproduce the yellow coloration using all or any of the solutions provided (1, 2, 3, 4, and 'a') as they wish. They are also asked to investigate further to determine as much as they can about both the effect and nature of each of the solutions. The students are asked to record on the sheet provided steps taken in their approach to the problem.

The second Piagetian Task (PT 2) was devised by the investigator and closely parallels PT 1 in its format. Both tasks deal with the manipulation of five colorless solutions and both require the reproduction of a yellow coloration. However in PT 2 the yellow color is produced by the mixing of only two solutions, 4 and 'b'. It is similar to PT 1 in that it involves the color-inhibiting solution, the sulphite solution. PT 2 also involves an interfering starch solution which produces a deep blue color in the presence of free iodine. The written and oral directions given for both tasks are identical although the solutions in the two tasks differ in their chemical composition. Both Piagetian tasks (PT 1 and PT 2) are presented in Appendix D together with directions for the preparation of the solutions involved in both tasks.

The fact that the group format administration of both tasks deviates from the traditional Piagetian interview technique was not considered to be an invalid approach for purposes of the present study. A recent study by Gray (1973) involving the development of a Piagetian-based written test reports that there was no significant difference between student performance on a written Piagetian test and an oral one. Further, both PT 1 and PT 2 were discussed beforehand with two University instructors for their criticism of the format used.

On the basis of their performance on PT 1 and PT 2 students were categorized into respective substages of cognitive level. The tasks served to identify students who, by virtue of their combinatorial ability, approached the problem in a systematic and logical manner. The step by step written solution to the tasks served to identify students who realized the totality of possibilities inherent in these tasks and were able to devise an appropriate strategy to fully investigate the tasks. Other studies (Buell and Bradley, 1972) have shown that although students are at an age where one would expect them to exhibit formal reasoning this is not always the case. Performance on the Piagetian tasks, together with performance on the Skemp Test, was used to identify students operating at the different levels of cognitive development.

The administration of the Piagetian tasks (PT 1 and PT 2) was carried out using the group format during the regular class period. Following the preliminary demonstration illustrating the production of the yellow coloration, the students were allowed 60 minutes to perform the two tasks. Each student was provided with the necessary solutions and chemical glassware for the tasks and worked individually at a laboratory station. Each student was asked to carefully record each step taken on the separate sheet provided for each task.

Both Piagetian tasks (PT 1 and PT 2) were administered to 86 students in three Chemistry 30X classes in the pilot study. The tasks were found to be a reasonable length for the students to complete in 60 minutes.

On the basis of the preliminary investigation of the Piagetian tasks (PT 1 and PT 2) a final version of these tasks was developed. Misunderstandings regarding the actual directions for the tasks were corrected and minor adjustments made in the technique of administration. Both the pilot study and main study administration of these instruments was carried out by the investigator and every attempt was made to ensure consistency of administration techniques in all classes used in the study.

The Co-operative School and College Ability Test

In order to obtain a measure of general ability, the grade nine Co-operative School and College Ability Test (SCAT) Form 3A scores for most of the students involved in the study were obtained from the Department of Education cumulative record cards. SCAT scores for 11 of the students in the sample were not available. Mean SCAT scores were substituted for these students.

The SCAT Form 3A test consists of two 30-item verbal parts and two 25-item quantitative parts for a maximum possible raw score of 110. SCAT scores have been widely used to predict students' ability to succeed in school work (Fowler, 1965, p. 322). The test-retest reliability of the Form 3A SCAT scores over a one year period is reported as being 0.93 (Tully and Hall, 1965).

The Testing Procedure

All of the instruments used in the study were administered by the investigator during the two week period prior to the Easter school break and the one week period immediately following the school holiday in May 1973. The tests were administered during regular class periods at the convenience of the cooperating teachers. Both the Chemistry Achievement Test (CHAT) and the Misconception Identification Test (MIT) were used by the three teachers involved in the final study as part of their regular evaluation of chemistry achievement. The students on all occasions were told beforehand of the schedule of testing and that the results of both the CHAT and the MIT were being recorded by their chemistry teacher. In this manner it was hoped that the scores obtained would more accurately reflect the students' true performance.

The class periods for each of the two schools involved in the study were 74 minutes in length and were therefore adequate for all the instruments, none of which required more than 60 minutes to complete.

The Chemistry Achievement Test (CHAT) was administered first in a regular class period followed by the Misconception Identification Test (MIT) the following day. This order was convenient to the cooperating teachers as they had recently taught the topics dealt with on the two instruments. Both the CHAT and the MIT were answered on general purpose IBM answer sheets.

For the CHAT each student was given a copy of the test booklet together with an IBM answer sheet and HB pencil. The students were told that the CHAT was an achievement test covering Chapters 7 to 10 in the CHEM Study course. The allowed time of 60 minutes was found to be adequate for all students to complete the test.

In a similar manner the MIT was administered by giving each student the direction sheet, the test booklet for the MIT, the reasoning sheet and an IBM answer sheet and HB pencil. During each administration of the MIT the sample question was worked through with the students and the separate sheet requiring the student to state his/her reasoning for responses to particular questions was fully explained.

The Skemp Test (SK6) was administered next during a regular class period. Each student was given the Practice Sheet, the Demonstration Sheet, and the SK6 (Part I) and the practice questions were worked through with the class. The Demonstration Sheet was then explained and the students given ten minutes to complete the SK6 (Part I). Following this, the answer sheet for the SK6 (Part I) was supplied to each student. The answers to SK6 (Part I) were discussed and student inquiries were answered to ensure that the basic operations were understood. The procedure for SK6 (Part II) was then explained, and the students given 30 minutes to complete the test. As the purpose of the SK6 (Part I) was only for the student to gain familiarity with the test operations, only the results of the SK6 (Part II) were considered for the study. The allotted time limit of 30 minutes for SK6 (Part II) was found to be adequate.

The two Piagetian tasks (PT 1 and PT 2) involving the combination of colorless chemical solutions were administered last during a regular class period in the chemistry laboratory. Each student was supplied with the necessary solutions, labels, chemical glassware and answer sheets for both tasks and worked individually at a laboratory station. Prior to the commencement of the tasks the investigator demonstrated the formation of the yellow color produced in each task. No indication of which solutions produced the color was given in the demonstration. The students were advised that they could start on either task (PT 1 or PT 2) but were required to attempt both. Generally, the 60 minute limit allowed for the two tasks proved adequate.

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

The results of the study are presented and discussed in this chapter. The chapter is organized into five principal sections. The first section presents the results of the Misconception Identification Test (MIT), the Chemistry Achievement Test (CHAT), the Skemp Test (SK6), the Piagetian Tasks (PT 1 and PT 2), and the general ability test (SCAT).

In the second section, the analyses relating to the major hypotheses, 1.0 and 2.0, are discussed. These analyses deal with the rate of incidence of specific misconceptions in chemical equilibrium and the relationship between student achievement in chemistry and performance on selected Piagetian Tasks.

The third section of the chapter deals with the analyses and discussion of results pertaining to the hypotheses 2.1, 2.2, 2.3 and 2.4.

The fourth section discusses the associated questions in the study as they relate to the hypotheses.

The fifth and final section of the chapter discusses the findings for the six major misconceptions separately from the viewpoint deemed most useful to the high school chemistry teacher.

The statistical calculations were executed on the University of Alberta IBM 360/367 computer, using the documented program of the Division of Educational Research Services (DERS). In the statistical analysis, the difference between criterion test scores and the correlation between test scores are considered statistically significant if the probability of observing such a relationship as a result of sampling error is 0.05 or less.

Statistical procedures associated with the treatment of each hypothesis are discussed in conjunction with the results.

Results of Tests

The Misconception Identification Test (MIT)

The Misconception Identification Test (MIT) is discussed in Chapter III. Results of the two versions of the Misconception Identification Test, MIT(A) and MIT(B), are presented in Table II. The distinction between the two versions of the MIT was made on the basis of the methods used in keying the test items. MIT(A) refers to the MIT when keyed accurately in a chemical sense. MIT(B) refers to the MIT when keyed according to the six major misconceptions that students may possess in the area of chemical equilibrium. Hence, each student is said to possess a performance score, as reflected by his performance on the MIT(A) and a misconception score, as reflected by his performance on the MIT(B). Item analysis for the MIT(A) and MIT(B) are presented in Appendix E.

The MIT(A) mean is equivalent to 45.3 percent and indicates the difficult nature of the test. This finding is consistent with the results of the initial form of the MIT(A) used in the pilot study. For the 62 students who wrote the MIT(A) in the pilot study, the mean was equivalent to 38.3 percent. The increase in the mean for the MIT(A) for the sample in the main study may be attributed to revisions

TABLE II

Intercorrelations, Means and Standard Deviations of the Test Scores

	MIT A	MIT B	CHAT	SK6 1	SK6 2	SK6 3	SK6 T	PT SCAT	V. SCAT	Q. SCAT	T. SCAT
MIT A	1.00										
MIT B	0.71	1.00									
CHAT	0.55	0.51	1.00								
SK6 1	0.15	0.17	0.24	1.00							
SK6 2	0.32	0.33	0.47	0.39	1.00						
SK6 3	0.21	0.08	0.21	0.45	0.33	1.00					
SK6 T	0.29	0.25	0.41	0.79	0.75	0.76	1.00				
PT 1	0.61	0.46	0.74	0.18	0.38	0.23	0.34	1.00			
V. SCAT	0.13	0.03	0.33	0.38	0.33	0.35	0.47	0.28	1.00		
Q. SCAT	0.13	0.21	0.37	0.33	0.42	0.23	0.43	0.29	0.44	1.00	
T. SCAT	0.15	0.14	0.41	0.42	0.44	0.34	0.53	0.29	0.85	0.84	1.00
Mean	13.6	18.6	19.4	10.9	10.5	6.0	27.5	2.8	44.4	34.1	78.5
Std. Dev.	3.3	3.9	5.0	3.2	3.3	3.1	7.4	0.7	8.4	8.1	14.0

carried out on the initial form of the MIT(A).

The standard deviation of 3.28 for the MIT(A) indicates that approximately two-thirds of the scores lie between the values of 10 and 16. The frequency distribution of the MIT(A) scores is given in Figure 1.

The MIT(B) mean is equivalent to 62.1 percent. The standard deviation for the MIT(B) indicates that about two-thirds of the scores lie between the values of 15 and 22. Figure 2 shows the frequency distribution of the MIT(B) scores.

A Kuder-Richardson 20 (KR-20) reliability coefficient of 0.49 was calculated from the MIT(A). This fairly low value was not entirely unexpected. As the test measures several different attributes dealing with various types of equilibria, a measure of the internal consistency of the test, as given by the KR-20, would not be expected to be particularly high, especially in the light of the difficult nature of the test. However, the fact that the reliability coefficient (KR-20) increased to 0.57 for the MIT(B) as a result of keying the items according to the misconceptions that students were expected to possess in chemical equilibrium was encouraging. This would suggest that the Misconception Identification Test has some reliability as an instrument for the purpose of identifying misconceptions in this area.

The relatively high correlation coefficient found to exist between MIT(A) and MIT(B), $(r = .71)$, is discussed in a later section of this chapter.

These findings are in general agreement with the consensus of the four chemistry teachers involved in the study, who felt that the MIT was a difficult, but valid test of material pertaining to chemical

FIGURE 1

Frequency Distribution of the MIT(A) Scores

Mean = 13.6

N = 99

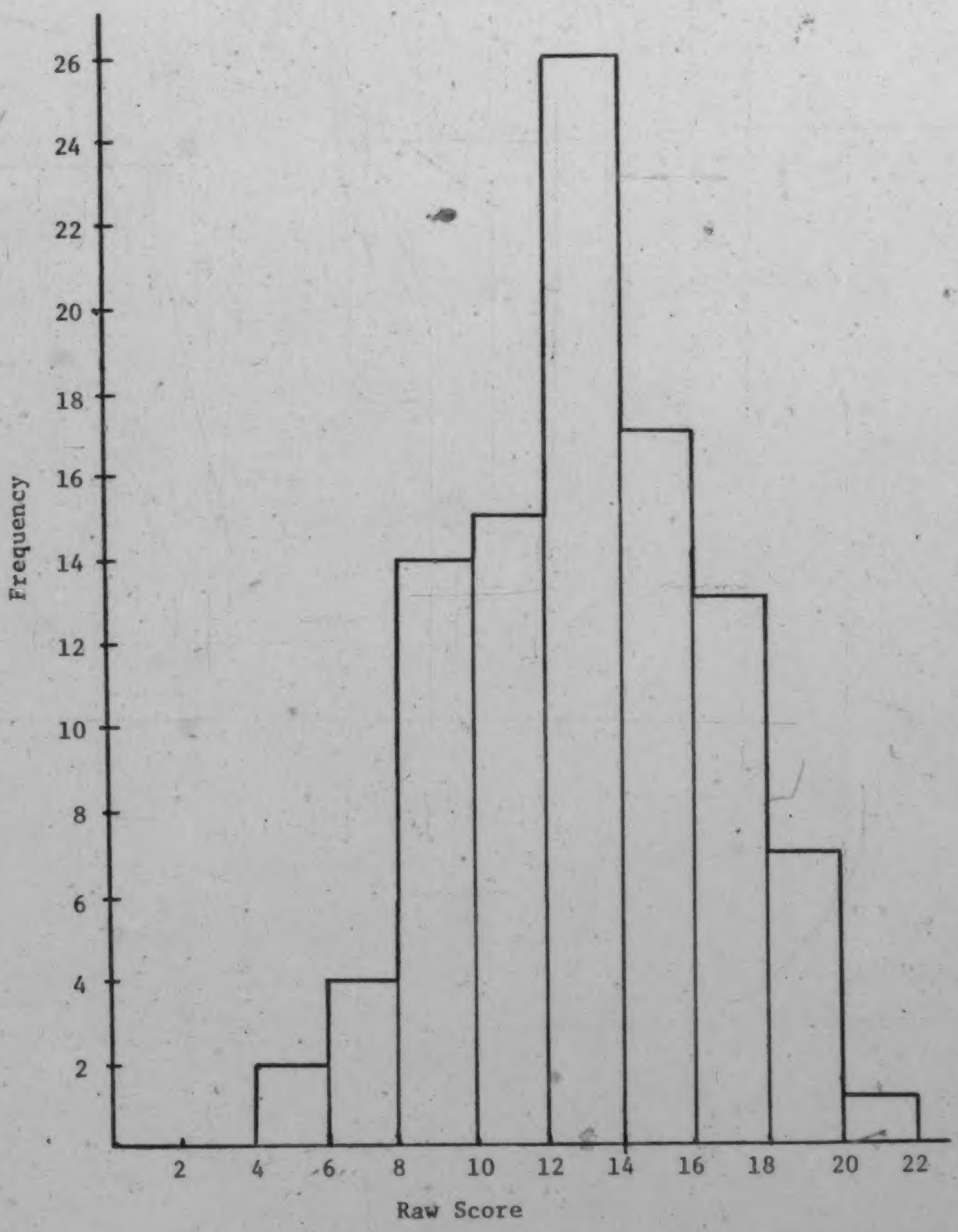
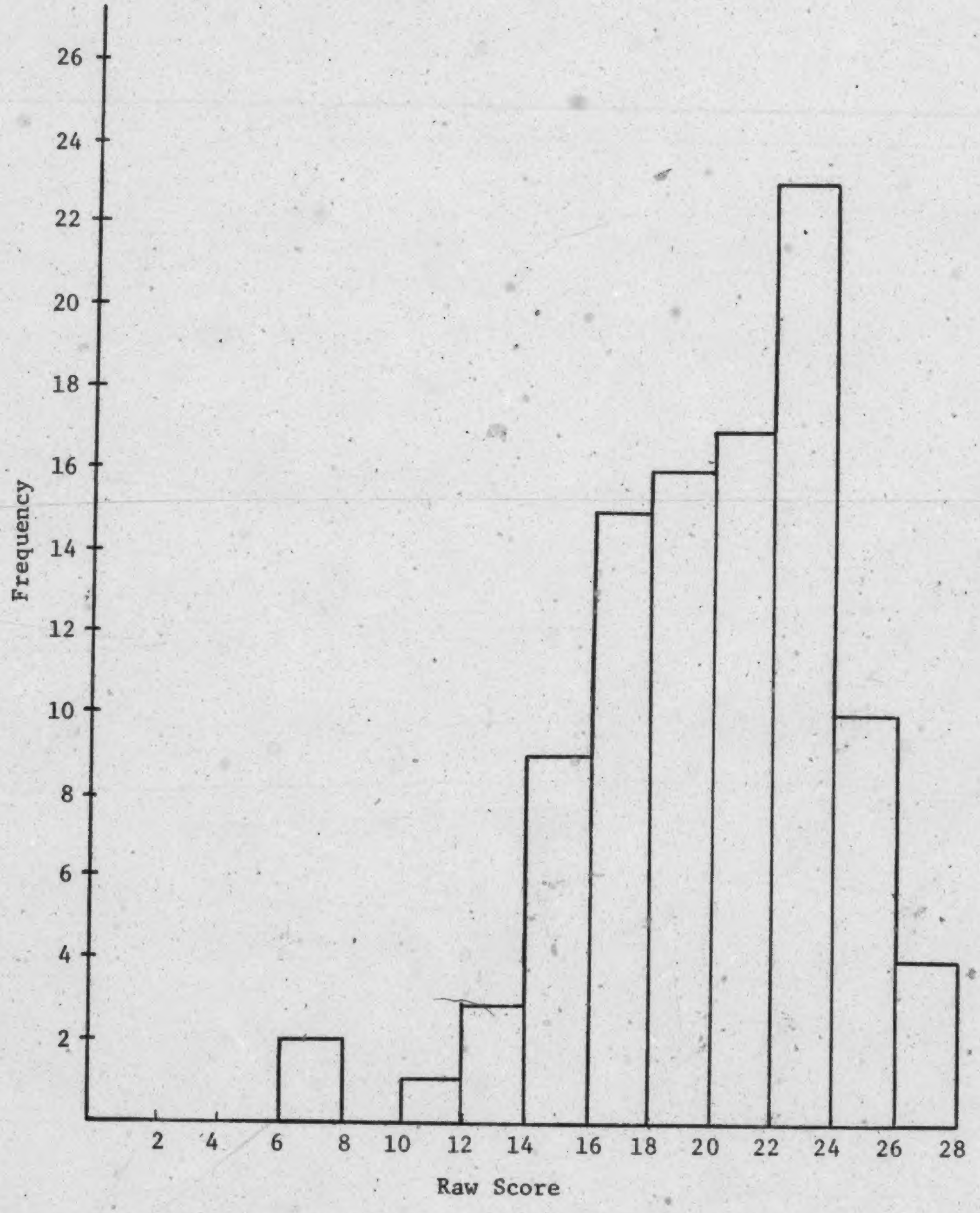


FIGURE 2

Frequency Distribution of the MIT(B) Scores

Mean = 18.6

N = 99



equilibrium in the CHEM Study text.

The Chemistry Achievement Test (CHAT)

The mean and standard deviation of the CHAT are reported in Table II. The CHAT mean is 59.1 percent and indicates that the students found the test fairly difficult. The Kuder-Richardson reliability coefficient (KR-20) of 0.75 is acceptable for an achievement test of this nature (Jackson and Ferguson, 1941). The CHAT was devised by Lantz (1972) and was found to have a reliability (KR-20) of 0.71 on the sample of 198 students in his study.

The standard deviation of 5.02 indicates that approximately two-thirds of the scores lie between 14 and 24. The frequency distribution of the CHAT scores given in Figure 3 shows a rather wide range of scores, with the highest frequency of scores occurring near the mean. In order to investigate how specific misconceptions and the number of misconceptions are related to different levels of achievement, the students in the study were divided into three nearly equal groups on the basis of their CHAT achievement scores. This was done by using the frequency distribution of the CHAT to establish, as nearly as possible, three groups of equal size (high, middle and low). Cutting points at 17 and 21 produced three nearly equal groups.

Table III shows the distribution of male and female students within the three achievement groups.

The percentage of 63.6 of boys and 36.4 of girls in the sample is in general agreement with other studies on the high school science population (Lantz, 1972; Walberg, 1967). A chi-square test of independence performed on the data indicates that there is no significant

FIGURE 3

Frequency Distribution of the CHAT Scores

Mean = 19.4

N = 99

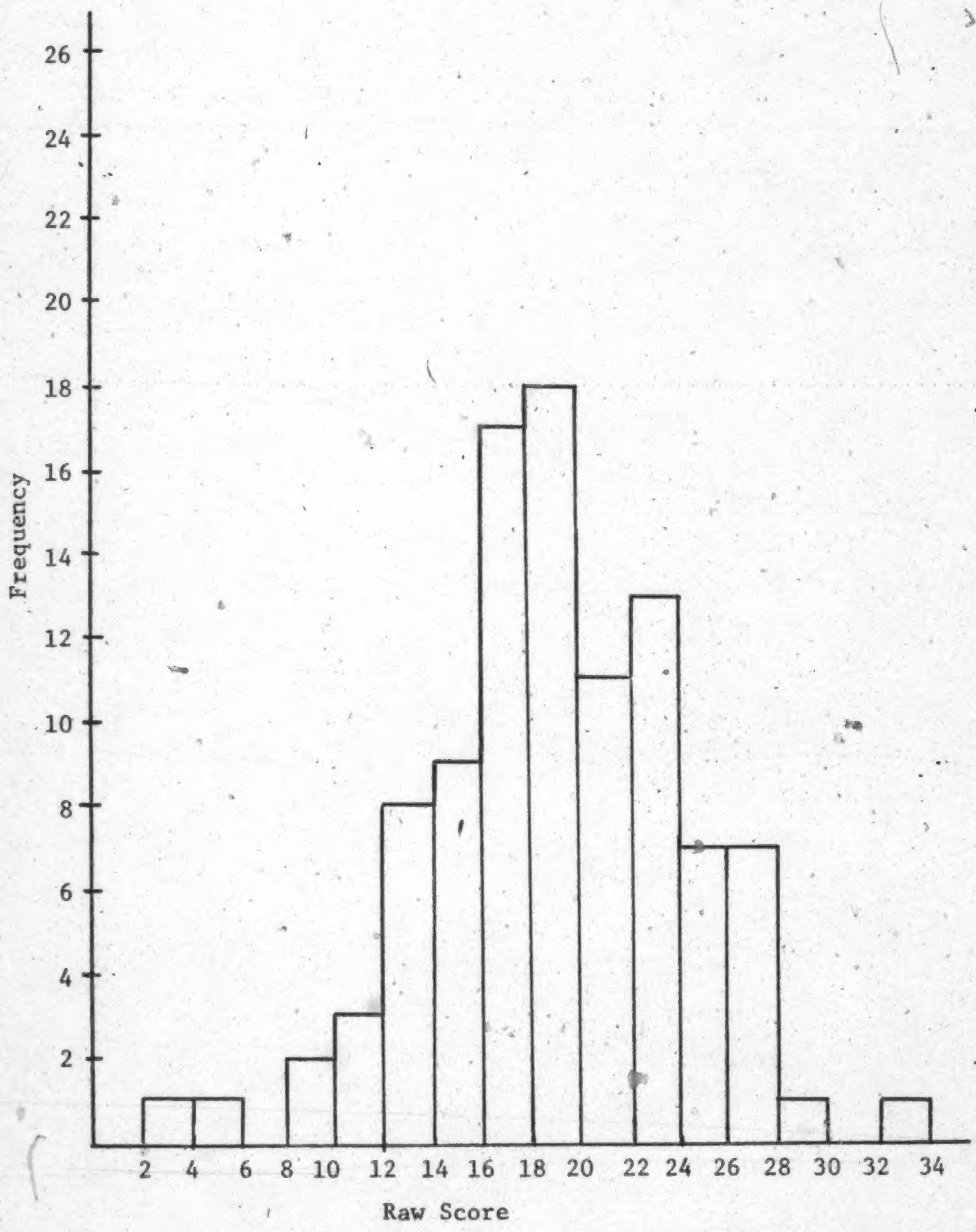


TABLE III

Distribution of Sample by Sex in Achievement Groups

High, Middle and Low

N = 99

Sex	High	Middle	Low	Total
Male	25	21	17	63
Female	11	9	16	36
Total	36	30	33	99

difference in performance on the CHAT for the two groups according to sex. In a similar manner both the number of misconceptions held by male and female students and specific misconceptions held were investigated to determine whether there was any significant difference between the two groups. No significant difference was found. This investigation is discussed in section three of this chapter. On the basis of the above results no further attempt to investigate the sex factor was undertaken in subsequent analyses.

The Skemp Test (SK6, Part II)

The mean and standard deviation of the SK6 are reported in Table II, together with the intercorrelations of the three sections of the SK6.

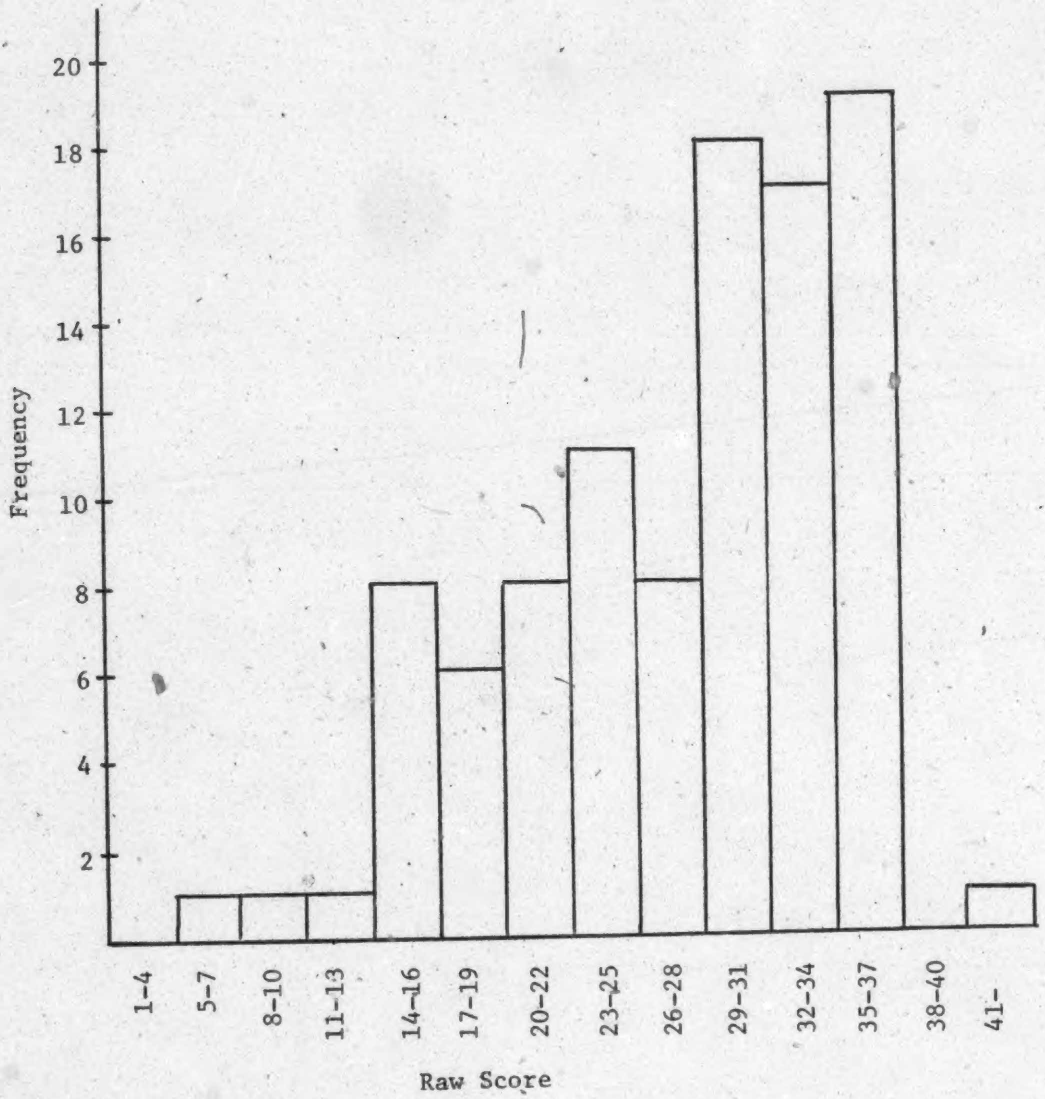
The mean of the total SK6 is equivalent to 61 percent of the possible total. The frequency distribution in Figure 4 shows a considerable range of scores. Means for the three sections of the SK6 test, SK6(1), SK6(2) and SK6(3), are equivalent to 72.5 percent, 70.6 percent and 40.1 percent respectively. The relatively low mean for the third section of the SK6 test is not unexpected in light of the view

FIGURE 4

Frequency Distribution of the SK6 Total Scores

Mean = 27.5

N = 99



that performance on this section is regarded as closely associated with formal operational thought.

As discussed in Chapter III, performance on the respective sections of the SK6 test is seen to be related to the cognitive level (F_2) and probably accounts for the apparent difficulty of the third section of the SK6.

A discussion of the results of the other Piagetian tasks (PT 1 and PT2) used to determine the cognitive level of the students in the sample follows.

The Piagetian Tasks (PT 1 and PT 2)

The Piagetian tasks, PT 1 and PT 2, were evaluated according to specified criteria based on extensive experiments described in Inhelder and Piaget (1958, p. 107-122) and presented in Chapter II.

In terms of levels of cognitive functioning the sample (N=99) was classified as follows:

Early Concrete (C_1) - 3 students
Late Concrete (C_2) - 24 students
Early Formal (F_1) - 61 students
Late Formal (F_2) - 11 students.

In gross terms, 73 percent of the students were found to be capable of using formal operations in their thinking with respect to these tasks and 27 percent were still limited to concrete operations. This is based on the assumption that the Piagetian tasks, as used in the study, give a valid indication of the levels of cognitive functioning. These results are in general agreement with other investigations in this area (Buell and Bradley, 1972; Hobbs, 1972) which indicate that the majority of high school students were capable of early formal thought (F_1).

It should be noted here that PT 1 and PT 2 were found to be equivalent tasks for purposes of the study. That is, performance on either task was indicative of the other. This finding arose as a result of initially attempting to evaluate student performance on each task separately according to the specified criteria. Comparison of the results for the first 40 students on both tasks, PT 1 and PT 2, proved totally consistent. For this reason, PT 1 was used to evaluate the remaining students' performance on these tasks. Since any reference to PT 1 is equally applicable in all respects to PT 2, the designation 'PT 1' will refer from this point on to the two tasks combined. This combined designation was also used in reporting results in Table II.

The Co-operative School and College Ability Test (SCAT)

The mean and standard deviation of the SCAT scores for the total population of Alberta Grade IX students who wrote the test in 1970 were obtained from the Department of Education. For the total population who wrote the SCAT, the mean score on the verbal section was 37.7 and the standard deviation was 10.3. For the students in the present study, the mean score on the verbal section is 44.3 with a standard deviation of 8.4. On the quantitative SCAT scores the population mean and standard deviation were 28.0 and 8.7, respectively. The corresponding quantitative SCAT scores for the sample have a mean of 34.1 and a standard deviation of 8.1. The total SCAT scores for the population had a mean of 65.7 and a standard deviation of 17.0. The mean and standard deviation of the total SCAT scores for the sample are 78.5 and 14.1 respectively.

SCAT scores for eleven students in the sample were not available. For these students the mean SCAT score for the sample was used in the analysis of the data. A test for the homogeneity of variance of the SCAT scores was performed beforehand to ensure that this decision was justifiable.

The higher means and smaller standard deviations of the SCAT scores of the sample indicate they are a comparatively select group. These findings would generally be expected for the total chemistry 30X population, as students of higher ability tend to enrol in chemistry and selection occurs prior to reaching chemistry 30X.

SCAT scores for the study sample are presented in Appendix E. The frequency distribution of the total SCAT scores appears in Figure 5.

Results and Discussions Related to the Major Hypotheses

Hypothesis 1.0

Hypothesis 1.0 states that the rate of incidence of specific misconceptions in chemical equilibrium consistently exceeds that expected by chance. Results of the item analysis on the MIT are presented in Table IV together with the chance value for the incorrect responses for each item and the chi square associated with the distribution of the incorrect responses.

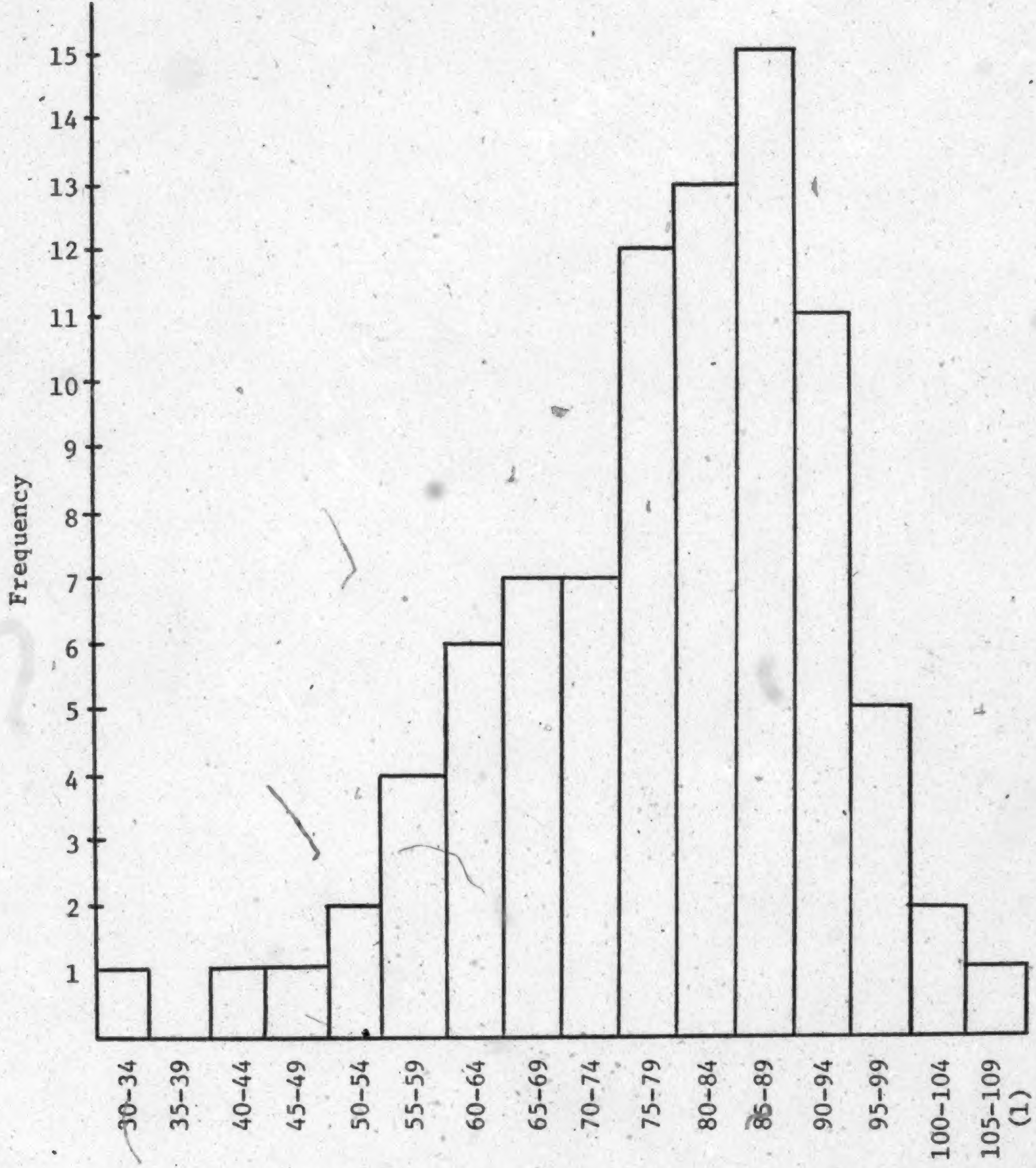
On all items the proportion of students choosing the response based on the keyed misconception consistently exceeds that expected by chance. The distribution of the incorrectly keyed answers yielded

FIGURE 5

Frequency Distribution of the Total SCAT Scores

Mean = 65.7

N = 88



Raw Score

TABLE IV

Item Analysis of the MIT: Chance Values and Chi Squares for Incorrect Responses

Item	Response				Chance Value	χ^2	Prob.
	A	B	C	D			
1	*.43	.42•	.14	.00	(.19)	49.0	x
2	.21•	*.55	.18	.06	(.15)	8.4	x
3	*.31	.35•	.27	.05	(.23)	21.6	x
4	*.70	.07	.23•	.00	(.10)	27.8	x
5	*.83	.03	.11•	.03	(.06)	7.5	xx
6	.08	*.68	.23•	.00	(.11)	26.4	x
7	*.27	.49•	.15	.07	(.24)	42.0	x
8	*.76	.06	.16•	.01	(.08)	15.2	x
9	.16	.28•	*.51	.04	(.16)	18.0	x
10	.52•	.16	.14	*.16	(.28)	33.5	x
11	.40•	.07	*.48	.04	(.17)	47.0	x
12	.14	*.03	.81•	.02	(.32)	112.1	x
13	.11	*.27	.60•	.02	(.24)	80.1	x
14	.10•	.08	*.80	.02	(.07)	5.2	xx
15	.75•	.20	.04	*.01	(.33)	84.1	x
16	.22	.70•	.05	*.02	(.33)	70.3	x
17	*.62	.19•	.17	.02	(.13)	13.6	x
18	.20•	*.70	.06	.04	(.10)	15.2	x
19	.14	.34•	*.39	.12	(.20)	12.8	x
20	.12•	*.83	.05	.00	(.06)	14.8	x
21	.88•	.04	.07	*.01	(.33)	137.6	x
22	.21	*.42	.23•	.12	(.19)	3.7	xx
23	*.26	.10	.62•	.02	(.25)	86.0	x
24	.06	*.80	.05•	.08	(.07)	0.7	xx
25	*.73	.15•	.06	.05	(.09)	7.0	xx
26	.07	.45•	*.42	.03	(.19)	58.6	x
27	.06	*.27	.63•	.03	(.24)	95.3	x
28	*.54	.26•	.17	.02	(.15)	19.6	x
29	.17	.27•	*.49	.04	(.17)	16.6	x
30	.60•	.07	*.28	.03	(.24)	86.8	x

* keyed answer
• keyed misconception
( ) chance value of incorrect responses
x = $p < .01$
xx = $p > .05$

significant chi squares ($p < .01$) on all items except five.

The six specific misconceptions investigated in the study were as follows:

Misconception 1: Mass vs. Concentration

Misconception 2: Rate vs. Extent of Reaction

Misconception 3: Constancy of Equilibrium Constant

Misconception 4: Misuse of Le Chatelier's Principle

Misconception 5: Constant Concentration

Misconception 6: Competing Equilibria.

In order to ascertain the extent to which the major misconception occurred, both a performance score and a misconception score were determined for each student for each of the six misconceptions. The MIT performance scores for each misconception were obtained by determining the number of items correctly answered by each student on the subtest of the MIT measuring the given misconception in MIT(A). For example, a student answering 3 out of the 5 item subtest dealing with misconception 4 on the MIT(A) correctly, would be given a performance score of 3 on misconception 4.

In a somewhat similar manner misconception scores for each student for each misconception were obtained using the MIT(B) scores. The misconception score refers to the number of items on the subtest dealing with a given misconception that a student obtains using the MIT(B) Key. It should be noted here that the performance score and the misconception score are closely related in the sense that both scores are obtained from the same test using different keys for the test. Further, once the performance score for a given student is obtained, restrictions are placed on the possible misconception score the student can obtain.

To illustrate, consider the case where a student answers three items correctly on the five item subtest dealing with misconception 4. The performance score for the student is therefore 3. The misconception score is found by determining how many of the items missed on the MIT(A) subtest can be attributed to a misconception as given by the MIT(B) test. In this case, if the two items incorrectly answered on the five item MIT(A) subtest are both consistent with the keyed response on the MIT(B) subtest, the student would be given a misconception score of 2 on this particular misconception. By this method misconception scores for each student on each of the six major misconceptions were calculated.

The decision was to whether a given student possesses a particular misconception was made on the basis of both the MIT performance and misconception scores. A misconception was said to be present if the misconception score accounted for 50 percent or more of the subtest incorrectly answered on the MIT(A) test. Using this criterion, the presence or absence of each of the six major misconceptions for each student, together with the total number of misconceptions possessed by each student was determined. The results are presented in Table V.

Table VI presents the distribution of the specific misconceptions within the sample. Misconception 4, the misuse of Le Chatelier's Principle, was found to be the most prevalent of the six major misconceptions studied, being held by 95 out of the 99 students in the study sample. Both misconceptions 1 and 2, the misconceptions of mass vs. concentration and rate vs. extent of reaction, respectively, occurred to the same extent and were found to be the least prevalent.

TABLE V

MIT Performance and Misconception Scores, Total Misconceptions and Cognitive Level for Sample

I.D. No.	Performance Scores						Misconception Scores						Total Misconceptions Present	Cognitive Level			
	Misconception						Misconception										
	1	2	3	4	5	6	1	2	3	4	5	6		C_1	C_2	F_1	F_2
100	2	4	5	1	3	5	2x	1	0	4x	0	2	2				x
101	2	3	1	2	1	5	2x	1	1x	3x	3x	2	4			x	
102	2	5	4	1	2	5	1x	0	0	3x	2x	2	3				x
103	4	3	1	1	2	5	0	1	4x	3x	2x	2	3				x
104	2	4	2	1	3	5	1x	1	3x	3x	1	2	3				x
105	3	3	2	0	0	5	1	2x	2x	5x	2x	2	4			x	
106	3	3	3	0	2	4	1	2x	0	5x	2x	3x	4			x	
107	3	3	3	1	0	5	1	1	1	4x	3x	2	2			x	
108	3	3	4	[illegible]	1	4	1	1	0	4x	2x	3x	3				x
109	3	4	2	1	3	5	1	0	3x	4x	1	2	2			x	
110	3	4	5	0	1	6	1	0	0	4x	3x	1	2				x
111	2	5	4	0	2	1	1x	0	1	4x	2x	3x	4			x	
112	2	2	2	2	1	5	1x	1	1	3x	2x	2	3			x	
113	2	3	2	2	1	6	2x	1	1	3x	2x	1	3			x	
114	3	3	3	0	2	6	1	1	2x	3x	2x	1	3			x	
115	2	4	2	1	1	4	1x	0	0	3x	3x	3x	4			x	
116	[illegible]	4	2	0	1	2	0	0	1	3x	3x	4x	3			x	
117	2	4	1	0	1	6	2x	1	3x	5x	3x	1	4			x	
118	3	5	4	0	1	2	1	0	1	3x	3x	5x	3			x	
119	3	3	1	0	1	3	1	2x	4x	5x	3x	2x	5			x	
120	3	4	1	0	3	2	1	1	1	3x	1	4x	2			x	
121	3	2	3	1	0	3	1	1	1	4x	4x	3x	3			x	
122	2	3	1	0	0	2	1x	1	2x	3x	3x	3x	5		x		
123	3	3	4	1	2	2	1	2x	0	2x	1x	2	3			x	
124	2	3	2	0	2	3	0	1	3x	4x	2x	3x	4			x	
125	3	2	2	1	1	4	1	1	2x	3x	3x	3x	4			x	
126	3	3	4	0	2	5	1	1	1	4x	2x	2	2			x	
127	3	3	2	0	1	3	1	2x	2x	4x	2x	4x	5			x	
128	2	2	3	1	2	1	2x	2x	0	1	2x	4x	4		x		
129	3	3	0	1	0	2	1	2x	3x	0	3x	3x	4			x	
130	2	5	2	1	1	1	1x	0	2x	3x	3x	4x	5		x		
131	3	3	4	1	2	4	1	1	0	3x	1	1	1			x	
132	2	3	0	1	1	1	1x	1	4x	3x	3x	3x	5			x	
133	4	4	1	1	1	2	0	0	2x	1	1	5x	2			x	
134	2	2	0	2	1	5	1x	2x	5x	2x	3x	0	5		x		
135	2	4	1	1	1	4	2x	0	1x	3x	3x	2	4		x		
136	3	2	3	1	3	3	0	1	2x	3x	0	3x	3			x	
137	2	3	3	0	1	1	1x	1	1	3x	3x	2	3		x		
138	2	4	5	0	1	6	1x	1	0	4x	3x	0	3			x	
139	1	2	3	1	1	2	2x	1x	1	1x	1x	4x	5		x		
140	3	2	4	2	3	5	0	2x	0	2x	1	2	2				x
141	3	4	1	0	0	2	1	1	2x	4x	4x	3x	4		x		
142	3	4	4	0	2	4	1	1	1	3x	2x	0	2			x	
143	2	3	4	1	2	4	1	2x	0	4x	2x	3x	4		x		
144	2	3	1	2	2	3	1	0	1	3x	2x	3x	3			x	
145	3	3	1	0	0	2	1	1	2x	3x	4x	2x	4			x	
146	3	4	5	1	0	4	0	1	0	4x	4x	3x	3				x
147	2	1	3	2	0	1	1	2x	0	2x	3x	4x	4		x		
148	2	2	1	1	2	2	2x	3x	0x	2x	2x	4x	6			x	
149	1	3	1	0	0	1	0x	1	1x	4x	3x	4x	5			x	

x indicates misconception present

TABLE V (continued)

MIT Performance and Misconception Scores, Total Misconceptions and Cognitive Level for Sample

I.D. No.	Performance Scores						Misconception Scores						Total Miscon- ceptions Present	Cognitive Level			
	Misconception						Misconception										
	1	2	3	4	5	6	1	2	3	4	5	6		C1	C2	F1	F2
150	4	4	5	0	3	3	0	0	0	4x	1	2x	2			x	
151	3	3	5	0	2	5	1	2x	0	5x	2x	2	3			x	
152	1	0	1	0	2	2	1x	3x	2x	2x	0	0x	5	x			
153	3	4	5	0	0	5	1	1	0	4x	4x	2	2				x
154	4	5	5	0	2	5	0	0	0	5x	2x	2	2				x
155	4	3	1	1	1	4	0	1	4x	3x	2x	1	3			x	
156	2	3	4	1	1	3	1	1	1	4x	2x	3x	3			x	
157	3	3	2	1	2	2	1	1	2x	1x	1	3x	3			x	
158	2	3	2	1	2	3	1	2	2x	3x	2x	2x	4		x		
159	2	4	0	0	1	6	1	1	5x	5x	3x	1	3		x		
160	3	4	4	0	4	5	1	1	1	3x	0	2	1				x
161	3	3	0	0	0	3	1	1	3x	3x	4x	2x	4			x	
162	1	4	4	0	0	3	2x	1	1	4x	4x	3x	4		x		
163	2	2	2	1	1	4	2x	1	1x	3x	2x	1	4		x		
164	1	2	3	1	0	4	1x	2x	0	3x	0	2	3		x		
165	3	5	1	0	1	2	1	0	1x	3x	1x	3x	4			x	
166	1	2	0	0	1	4	0x	3x	3x	3x	1x	1	5		x		
167	3	3	4	1	0	5	1	2x	1	4x	4x	1	3			x	
168	2	3	3	1	0	3	1	0	1	4x	4x	1x	3		x		
169	3	4	1	0	1	6	0	0	4x	4x	3x	1	3			x	
170	4	3	4	1	1	2	0	0	1	3x	3x	2x	3			x	
171	2	3	4	1	1	2	2x	2x	1	4x	2x	3x	5		x		
172	3	5	4	0	1	6	1	0	0	5x	3x	1	2			x	
173	2	2	0	0	2	5	1	3x	4x	3x	2x	0	4			x	
174	3	3	1	0	1	2	1	2x	4x	3x	3x	3x	5			x	
175	3	3	2	2	2	1	1	2	2x	3x	1	5x	3			x	
176	4	4	5	0	1	1	0	1	0	4x	2x	6x	3			x	
177	3	2	5	1	0	3	1	2x	0	3x	4x	3x	4			x	
178	3	3	4	1	2	3	0	1	0	3x	2x	4x	3		x		
179	3	3	2	1	3	1	0	2	1x	4x	1	5x	3			x	
180	3	3	2	1	0	1	1	2x	2x	4x	4x	5x	5			x	
181	2	3	4	1	1	6	0	1	0	3x	3x	1	2			x	
182	2	2	1	1	0	2	1	2x	2x	3x	2x	4x	5		x		
183	4	4	3	1	1	3	0	1	2x	4x	2x	4x	4			x	
184	3	5	2	2	1	3	1	0	1x	3x	3x	0x	4			x	
185	2	4	2	2	2	2	1	1	0	1x	2x	2x	3			x	
186	3	3	0	1	1	3	1	2x	3x	3x	2x	2x	5			x	
187	3	4	2	2	0	2	1	0	2x	3x	3x	1x	4			x	
188	2	4	0	0	3	4	2x	0	0	3x	1	3	2			x	
189	2	4	4	0	1	4	1x	1	0	4x	3x	3	3		x		
190	3	4	4	1	1	1	1	1	1	4x	3x	4x	3			x	
191	4	4	5	1	1	3	0	1	0	2x	3x	3x	3			x	
192	2	2	2	0	0	3	2x	2x	1x	2x	3x	3x	6	x			
193	2	3	3	0	0	2	1	1	0	3x	3x	3x	3		x		
194	3	1	1	0	1	3	1	3x	1x	4x	2x	1x	5		x		
195	4	1	0	0	1	3	0	1x	2x	2x	3x	2x	5		x		
196	3	3	2	1	1	3	1	2x	3x	2x	2x	2x	5			x	
197	1	4	4	2	2	1	1	1	0	3x	2x	3x	3		x		
198	3	4	2	1	2	5	1	1	1	4x	1x	2	2			x	

TABLE VI

Distribution of Sample Possessing Specific Misconceptions

N = 99

	Possessed Misconceptions					
	1	2	3	4	5	6
Number of Students	29	29	47	95	84	60

TABLE VII

Distribution of Sample Showing Number of Misconceptions Held

N = 99

	Number of Misconceptions Held					
	1	2	3	4	5	6
Number of Students	2	16	36	25	18	2

The distribution of the total number of misconceptions held by the study sample is presented in Table VII. This refers to the actual number of misconceptions out of the six possible. Results indicate that 82 percent of the sample possessed three or more of the six misconceptions identified. Almost half of the students (45%) held four or more of the six misconceptions.

These findings clearly indicate that students do possess misconceptions in the area of chemical equilibrium. The rate of incidence of specific misconceptions was found to consistently exceed that expected by chance. Further, of the six major misconceptions under investigation, each student in the sample was found to possess an average of 3.5 misconceptions.

There appears no evidence for the rejection of hypothesis 1.0.

Hypothesis 2.0

Hypothesis 2.0 states that there is no significant relationship between student achievement in chemistry as measured by the CHAT and performance on selected Piagetian Tasks. The intercorrelations of the CHAT with the three sections of the Skemp Test (SK6), the total performance score on the SK6, and the Piagetian Tasks, PT 1, are presented in Table II (p. 83). All correlation coefficients exceed the critical value of 0.20 (df=98) at the .05 level of significance.

Of the two types of Piagetian Tasks, PT 1 has the highest correlation with the CHAT scores ($r = .74$, $p < .001$). To determine the extent to which performance on PT 1 contributes to the variance of the achievement scores, a stepwise regression analysis was carried out on the prediction of the CHAT using the Piagetian Tasks as predictor variables.

The stepwise regression procedure makes use of the correlation matrix for the predictor variables and enters into regression the variable most highly correlated with the variable being predicted, in this case the CHAT score. Using the partial correlation coefficients as before, it then selects, as the next variable to enter the regression equation, that predictor whose partial correlation with the CHAT score is highest. This process continues with the re-examination at every stage of the regression of the variables incorporated into the model in previous stages. Any entering predictor variable which provides a nonsignificant contribution is removed from the model. This process is continued until all significantly contributing predictor variables enter the regression equation (Draper and Smith, 1966, p. 171-173).

The results of the stepwise regression analysis for the prediction of achievement in chemistry from the Piagetian tasks are presented in Table VIII. The first variable entering the regression equation is the PT 1 score which accounts for 54.3 percent of the variance in the CHAT scores. The second variable to enter the regression equation is the SK6(2) score which increases R^2 to 58.7 percent. Both the quantitative and verbal scores on the SCAT, which were also included in the analysis as predictor variables, did not significantly contribute to the variance in the CHAT over and above the contribution of PT 1 and SK6(2). This suggests that performance on the Piagetian tasks, PT 1 and SK6(2), may be better predictors of achievement in chemistry than general ability. The regression equation for the prediction of CHAT scores from PT 1 and SK6(2) is presented with Table VIII.

Of the three sections of the Skemp Test, the only section that enters the regression equation significantly is the SK6(2) section.

TABLE VIII

Prediction of CHAT Scores from a Combination of Piagetian Tasks, PT1, SK6(1), SK6(2), SK6(3) and SCAT Scores

Predictor Variable Entering	F Value for Variable Entering	Total F Value	Probability Level for Last Variable Entering	R^2 (percent)
PT1	115.3	115.3	<.001	54.3
SK6(2)	10.3	68.3	.002	58.7

The regression equation in raw-score form is given by:

$$\hat{Y}_{CHAT} = 0.35\, X_{SK6(2)} + 4.9\, X_{PT1} + 1.9$$

This section displayed the highest correlation to achievement in chemistry ($r = .47$, $p < .001$). The fact that a large proportion of the sample (73%) was found to be capable of formal thought as determined from their performance on PT 1 would suggest that the SK6(2) scores might be more discriminating with respect to achievement scores as performance on SK6(2) is more indicative of formal thinking. That is, the items on the SK6(2) section of the Skemp test involve transformations associated with either the early or later formal levels of cognitive development. One would not expect the SK6(3) scores to contribute to the achievement scores as only 11 percent of the sample were deemed capable of late formal thinking according to performance on PT 1. Of the three portions of the Skemp Test, SK6(3) displayed the lowest correlation with CHAT ($r = 0.21$, $p = 0.033$). The correlation between PT 1 and SK6(T) was found to be 0.34 ($p < .001$). The section of the SK6(T) most highly correlated with PT 1 was, as expected, SK6(2), ($r = 0.38$, $p < .001$).

The means and standard deviations of all tests for each of the three achievement groups are presented in Table IX. The mean of 3.3 for the high group on the PT 1 indicates that most students in this group are capable of formal thinking. The means for the middle and low achievement groups on PT 1 indicate that the majority of students in these groups are operating at the level of late concrete thinking.

Scheffé's multiple comparison of means of the PT 1 scores shows that the scores for the low group are significantly different from the middle ($p = .001$) and high ($p < .001$) groups. The scores of the middle and high groups are also significantly different ($p = .008$). That is, even though the middle and low groups all operate at the level of concrete thinking, there is an apparent significant difference within

TABLE IX

Test Score Means and Standard Deviations for the Three Achievement Groups

Test		High	Middle	Low
MIT(A)	mean	15.8	12.3	12.3
	S.D.	3.2	2.6	2.7
MIT(B)	mean	20.9	17.8	16.8
	S.D.	3.0	3.6	3.8
CHAT	mean	24.6	19.2	14.1
	S.D.	2.5	1.0	3.3
SK6(1)	mean	11.9	11.0	9.7
	S.D.	2.4	3.3	3.5
SK6(2)	mean	12.6	9.7	9.2
	S.D.	2.3	3.7	2.8
SK6(3)	mean	6.8	5.8	5.3
	S.D.	2.7	3.5	3.2
SK6(T)	mean	31.4	26.6	24.0
	S.D.	4.5	8.0	7.6
PT1	mean	3.3	2.8	2.3
	S.D.	0.5	0.4	0.6
V.SCAT	mean	46.5	33.1	37.4
	S.D.	11.1	19.7	14.4
Q.SCAT	mean	36.8	23.8	29.1
	S.D.	9.7	15.4	11.5
T.SCAT	mean	83.4	56.8	66.5
	S.D.	19.0	34.0	24.5

the concrete level (i.e., the substages of the cognitive level).

The reported means for the three achievement groups of the CHAT scores in Table IX indicate a small standard deviation for the middle achievement group. This is due to the manner in which the achievement groups were defined. The high frequency of scores near the mean made it necessary to choose upper and lower limits of the middle group close together in order to achieve three groups of nearly equal size.

Table X presents the results of the one-way analysis of variance for the test scores. Both Piagetian task scores, SK6(T) and PT 1, are significantly different ($p < .001$) for the three groups. An examination of the results of the analysis of variance for the three sections of the Skemp test reveals that only the SK6(2) scores are significantly different for the three groups at the 0.01 level. This is consistent with the stepwise regression analysis discussed earlier.

It should be noted that for both the verbal and quantitative sections of the SCAT, the respective mean for the low achievement group exceeds that of the middle group. This result is not evident from the analysis of variance results for the SCAT scores which found significant differences on both the V. SCAT and Q. SCAT for the three achievement groups ($p < .01$). However, as discussed earlier in this section, neither the verbal nor quantitative sections of the SCAT scores contributed significantly to the regression analysis carried out for the prediction of CHAT scores. In this light comparatively little importance is placed on the significant differences for the three groups based on the SCAT scores.

On the basis of the results presented, hypothesis 2.0 is rejected. There appears to be a significant relationship between student achievement

TABLE X

One-way Analysis of Variance on the Test Scores

Test	Source	DF	SS	MS	F	P
MIT A	groups error	2 96	281.3 788.9	140.6 8.2	17.11	<.001
MIT B			318.6 1150.3	159.3 11.9	13.30	<.001
CHAT			1898.3 602.3	949.1 6.3	151.29	<.001
SK6(1)			83.3 908.5	41.6 9.5	4.40	0.015
SK6(2)			234.5 841.3	117.3 8.8	13.38	<.001
SK6(3)			39.9 924.1	19.9 9.6	2.1	0.132
SK6(T)			959.1 4457.6	479.5 46.4	10.33	<.001
PT1			15.4 27.9	7.7 0.3	26.53	<.001
V.SCAT			3161.1 22302.9	1580.6 232.3	6.80	0.002
Q.SCAT			2852.4 14343.2	1426.2 149.4	9.55	<.001
T.SCAT			12076.0 65510.6	6038.0 682.4	8.85	<.001

in chemistry as determined by the CHAT and performance on the Piagetian tasks, PT 1 and SK6.

The relationship established between achievement in chemistry and performance on the Piagetian tasks is taken into consideration in the testing of the remaining hypotheses.

Results and Discussion Related to Hypotheses 2.1, 2.2, 2.3 and 2.4

Hypothesis 2.1

Hypothesis 2.1 states that there is no significant relationship between the number of misconceptions a student demonstrates in solving selected problems in chemical equilibrium and performance on selected Piagetian tasks. The Pearson product-moment coefficients between MIT(A) and MIT(B) and the Piagetian tasks, PT 1 and SK6, are presented in Table II (p. 83). All correlation coefficients are significant at the .01 level.

The highest correlation exists between MIT(A) and PT 1, ($r = 0.61$, $p < .001$). It might be noted that although the total Skemp test, SK6(T), is significantly related to both MIT(A) and MIT(B), the three sections of the SK6 again vary considerably in their relationship to MIT(A) and MIT(B). SK6(2) has the highest correlation coefficient in both cases. The SK6(2) section of the Skemp test also displays the highest correlation with the SCAT scores, ($r = 0.47$, $p < .001$). This would be expected as performance on both the MIT(A) and MIT(B), like the CHAT, is basically a measure of achievement in chemistry. This is in addition to the specific purpose of the MIT in identifying major misconceptions in chemical equilibrium.

Further evidence for the relationship between the number of misconceptions possessed and performance on the Piagetian tasks was obtained by carrying out the stepwise regression analysis for the prediction of both the MIT(A) and MIT(B) scores using various combinations of predictor variables. Results of these analyses are presented in Tables XI and XII. For the prediction of MIT(A), PT 1 was found to be the only significant predictor variable ($R^2 = .37.5$, $F = 58.2$, $p < .001$) entering into the regression equation. None of the SK6 sections contributed significantly to the prediction over and above the PT 1.

When a further stepwise regression analysis was performed using the CHAT score as an additional predictor variable, no significant effect on the regression equation for MIT(A) was observed.

However when the CHAT scores were included in the prediction of MIT(B) scores in addition to the Piagetian tasks, PT 1 and SK 6, they were found to be the only significantly contributing predictor variables in the equation ($R = 26.4$, $F = 34.7$, $p < .001$). Apparently a considerable amount of the variance contributed by the PT 1 is common to the CHAT in relation to MIT(B). This result is interesting because, although the PT 1 and CHAT are highly correlated ($r = 0.74$, $p < .0001$), the CHAT scores do not enter the regression in the prediction of MIT(A) scores. This supports the contention that MIT(A) and MIT(B) are two distinct tests as used in the study.

Table XIII presents the distribution of the number of possessed misconceptions within the cognitive levels and substages of each level as measured by performance on PT 1. The distribution clearly indicates that the number of misconceptions possessed by the sample is related to the cognitive level of the student. Approximately 70 percent of the students at the early or late concrete level were found to possess more

TABLE XI

Prediction of MIT(A) Scores from a Combination of Piagetian Tasks, PT1, SK6 and SCAT Scores

Prediction Variable Entering	F Value for Variable Entering	Total F Value	Probability Level for Last Variable Entering	R^2 (percent)
PT1	58.2	58.2	<.001	37.5

The regression equation in raw-score form is given by:

$$\hat{Y}_{MIT(A)} = 3.0X_{PT1} + 5.0$$

TABLE XII

Prediction of MIT(B) Scores from a Combination of Piagetian Tasks, PT1 and SK6, CHAT Scores and SCAT Scores

Prediction Variable m Entering	F Value for Variable Entering	Total F Value	Probability Level for Last Variable Entering	R^2 (percent)
CHAT	34.7	34.7	<.001	26.4

The regression equation in raw-score form is given by:

$$\hat{Y}_{MIT(B)} = 0.4X_{CHAT} + 11.0$$

TABLE XIII

Distribution of the Number of Possessed Misconceptions Over Cognitive Level

COGNITIVE LEVEL

Number of Possessed Misconceptions	CONCRETE		FORMAL		Total
	Early	Late	Early	Late	
1	-	-	1	1	2
2	-	-	11	5	16
3	-	8	23	5	36
4	-	8	17	-	25
5	2	8	8	-	18
6	1	-	1	-	2
Total	3	24	61	11	99

than three of the six major misconceptions. Only 36 percent of the students at either the early or late formal level held more than three major misconceptions.

The results of a chi square test of independence between the number of misconceptions held and cognitive level are presented in Table XIV. The categorization of three misconceptions or less and more than three misconceptions was chosen as it divided the sample into two nearly equal groups.

TABLE XIV

Chi Square Test of Independence: Number of Misconceptions vs. Cognitive Level

Number of Misconceptions	Cognitive Level Concrete	 Formal	 Total
3 or less	8	46	54
over 3	19	26	45
Total	27	72	99

$\chi^2 = 9.3$ (df=1)

$(.001 < p < .01)$

As a result of the findings presented above, hypothesis 2.1 is rejected. There appears to be a significant relationship between the number of misconceptions held by students and their performance on the Piagetian tasks.

A consideration of the relationship between specific misconceptions and performance on the Piagetian tasks follows.

Hypothesis 2.2

Hypothesis 2.2 states that there is no significant relationship between selected misconceptions in chemical equilibrium and performance on the Piagetian tasks. The results of the chi square tests of independence performed for each of the six major misconceptions according to cognitive level are presented in Table XV.

Only misconception 1 (mass vs. concentration) and misconception 2 (rate vs. extent) were found to be significantly related to cognitive level. It might be noted that misconceptions 1 and 2 occurred to the same extent and were the least prevalent of the six misconceptions under investigation. The fact that the relationship between misconception 1 (mass vs. concentration) and cognitive level was found to be highly significant ($p < .001$) suggests that these concepts are not truly understood until some degree of formal operational thought is present.

The remaining four misconceptions, although highly prevalent in the sample, do not appear to be related to cognitive level as measured by PT 1. Each of the six specific misconceptions is discussed more fully in section five of this chapter.

On the basis of the significant relationship between misconceptions 1 and 2 and performance on the PT 1, hypothesis 2.2 is rejected for these misconceptions.

Hypothesis 2.3

Hypothesis 2.3 states that there is no significant relationship between the number of student misconceptions in chemical equilibrium and achievement in chemistry.

TABLE XV

Contingency Tables: Major Misconceptions According to Cognitive Level

		Cognitive Level		
		C	F	
Misconception 1	pres.	15	14	29
	abs.	12	58	70
		27	72	99

$\chi^2 = 12.3, \quad p < .001$

		Cognitive Level		
		C	F	
Misconception 2	pres.	13	16	29
	abs.	14	56	70
		27	72	99

$\chi^2 = 6.4, \quad .01 < p < .02$

		Cognitive Level		
		C	F	
Misconception 3	pres.	14	33	47
	abs.	13	39	52
		27	72	99

$\chi^2 = .29, \quad .50 < p < .70$

		Cognitive Level		
		C	F	
Misconception 4	pres.	26	69	95
	abs.	1	3	4
		27	72	99

$\chi^2 = 0.02, \quad .80 < p < .90$

		Cognitive Level		
		C	F	
Misconception 5	pres.	25	59	84
	abs.	2	13	15
		27	72	99

$\chi^2 = 1.7, \quad .10 < p < .20$

		Cognitive Level		
		C	F	
Misconception 6	pres.	19	41	60
	abs.	8	31	39
		27	72	99

$\chi^2 = 1.5, \quad .20 < p < .30$

The two versions of the Misconception Identification Test, MIT(A) and MIT(B), were found to be highly correlated ($r = 0.71$, $p < .001$). In turn MIT(A) and MIT(B) exhibit significant correlation coefficients with the CHAT scores, $r = 0.55$ and $r = 0.51$, respectively. In order to determine the effect of the achievement score (CHAT) upon the relationship between MIT(A) and MIT(B), a first order partial correlation coefficient was calculated (Ferguson, 1971, p. 390-392).

The partial correlation between MIT(A) and MIT(B), eliminating the effect of achievement, was found to be 0.61. Using this value, the percentage of the total variance of the MIT(B) in common with the achievement scores was found to be 26.2 percent. This is consistent with the result obtained using the stepwise regression analysis for the prediction of MIT(B) scores from a combination of predictor variables as presented in Table XII. The CHAT score was found to be the only significant variable entering the equation ($R^2 = 26.4$, $F = 34.7$, $p < .001$). Neither the SCAT scores nor the Piagetian tasks, PT 1 and SK6, enter into the prediction equation. Apparently the variance ratio of the CHAT to these various predictors is similar. This suggests that the number of misconceptions, as measured by MIT(B), is related to achievement in chemistry.

The distribution of the number of misconceptions within the three achievement groups is presented in Table XVI. Fifty-seven percent of the students in the low achievement group possessed more than three misconceptions compared to 30 percent in the high achievement group. A significant chi square ($\chi^2 = 12.37$, $.001 < p < .01$) was found between the number of misconceptions held by the sample and achievement in chemistry.

TABLE XVI

Chi Square Test of Independence: Number of Misconceptions vs. Achievement Group

Achievement

		High	Middle	Low	Total
Number of Misconceptions	less than 3	(6.5) 13	(5.5) 3	(6.0) 2	18
	3 or more	(29.2) 23	(24.8) 27	(27.0) 31	81
	Total	36	30	33	99

$\chi^2 = 12.37$, $df = 2$, $.001 < p < .01$

There appears to be a significant relationship between the number of misconceptions a student possesses in chemical equilibrium and achievement in chemistry. Hypothesis 2.3 is rejected.

A consideration of the relationship between specific misconceptions and achievement in chemistry follows.

Hypothesis 2.4

Hypothesis 2.4 states that there is no significant relationship between selected misconceptions in chemical equilibrium and achievement in chemistry. Table XVII presents the 2x3 contingency tables for each of the six major misconceptions according to the three achievement groups.

Three of the six misconceptions, numbers 3, 4 and 6, yielded significant chi squares at the .05 level. Of these, misconception 6, that of 'competing equilibria,' yielded the greatest value for chi square ($\chi^2 = 13.42$, $p = .001$). Misconception 6 refers to the inability of students to take into consideration all possible factors or variables that may affect the equilibrium condition of a chemical system. This suggests that the inability to control all possible variables in problems of chemical equilibrium may be related to achievement in chemistry.

Although misconceptions 1 and 2 were found earlier to be related to cognitive level, no relationship between these misconceptions and achievement was observed. Similarly misconception 5, that of 'constant concentration,' was not found to be related to achievement.

On the basis of these results, hypothesis 2.4 is rejected. There appears to be a significant relationship between certain misconceptions

TABLE XVII

Contingency Tables: Major Misconceptions According to Achievement Group

		Achievement				
		high	middle	low	Total	
Misconception 1 (mass vs. concentration)	present	(10.5) 10	(8.8) 7	(9.7) 12	29	$\chi^2 = 1.35$
	absent	(25.5) 26	(21.2) 23	(23.3) 21	70	$p = 0.509$
	Total	36	30	33	99	

		Achievement				
		high	middle	low	Total	
Misconception 2 (rate vs. extent)	present	(10.5) 7	(8.8) 9	(9.7) 13	29	$\chi^2 = 3.32$
	absent	(25.5) 29	(21.2) 21	(23.3) 20	70	$p = 0.190$
	Total	36	30	33	99	

		Achievement				
		high	middle	low	Total	
Misconception 3 ('Constancy' of constant)	present	(17.1) 11	(14.2) 18	(15.7) 18	47	$\chi^2 = 6.68$
	absent	(18.9) 25	(15.8) 12	(17.3) 15	42	$p = 0.035$
	Total	36	30	33	99	

TABLE XVII (continued)

Contingency Tables: Major Misconceptions
According to Achievement Group

		Achievement				
		high	middle	low	Total	
Misconception 4 (Le Chatelier's Principle)	present	(34.5) 36	(28.8) 30	(31.7) 29	95	$\chi^2 = 8.34$
	absent	(1.5) 0	(1.2) 0	(1.3) 4	4	$p = 0.015$
	Total	36	30	33	99	

		Achievement				
		high	middle	low	Total	
Misconception 5 (Constant Concentration)	present	(30.5) 30	(25.5) 27	(28.0) 27	84	$\chi^2 = 0.92$
	absent	(5.5) 6	(4.5) 3	(5.0) 6	15	$p = 0.631$
	Total	36	30	33	99	

		Achievement				
		high	middle	low	Total	
Misconception 6 (Competing Equilibria)	present	(21.8) 14	(18.2) 19	(20.0) 27	60	$\chi^2 = 13.42$
	absent	(14.2) 22	(11.8) 11	(13.0) 6	39	$p = .001$
	Total	36	30	33	99	

a student possesses in chemical equilibrium and achievement in chemistry.

Associated Questions

The three associated questions presented in Chapter I have been dealt with in the treatment of the major hypotheses. However, they are included here for purposes of clarity.

Question 1. Is there a significant difference between male and female students in the number of misconceptions in chemical equilibrium?

No significant sex difference in the number of possessed misconceptions was found. The chi square test of independence proved nonsignificant. Similarly, the distribution of the sample, by sex, for the total number of misconceptions proved nonsignificant.

Question 2. Is there a significant relationship between specific misconceptions and the sex of the student?

Chi square for each of the six major misconceptions, by sex, proved nonsignificant. Although specific misconceptions were found to be related to both cognitive level and achievement in chemistry, no sex factor was observed.

Question 3. Is the degree of student misconceptualization in chemical equilibrium related to mathematical ability?

The only measure of mathematical ability available to the study was the quantitative section of the students' Grade Nine SCAT score. Using this measure, no significant relationship between either the number of misconceptions held or specific misconceptions held and mathematical ability was observed. In the prediction of both the MIT(A) and MIT(B), the Q. SCAT was not a significantly entering predictor variable. Further, the Pearson product-moment correlation coefficient between MIT(A) and the Q. SCAT did not achieve significance at the .05 level ($r = .13$).

The following section discusses the six major misconceptions in light of the results presented in this chapter.

Discussion of Major Misconceptions

The results related to the six major misconceptions are discussed here in turn.

Table I in Chapter II presented the items of the MIT indicating the relevant misconception corresponding to each item. Means and standard deviations for the MIT subtests are presented in Table XVIII. Intercorrelations of the six subtests of the MIT are presented in Table XIX and indicate that the subtests are essentially independent of each other.

Misconception 1. *Mass vs. Concentration*

Students have difficulty in clearly distinguishing between the two basic and quite different concepts of mass and concentration.

The confusion between the two concepts shows up when students are asked to consider the following equilibrium:

$$CO_{(g)} + Cl_{2(g)} \rightleftharpoons COCl_{2(g)} + \text{heat.}$$

They are then asked to predict the effect on the equilibrium mass (number of moles) and concentration of CO when the volume of the system is halved by increasing the pressure at constant temperature. Although 68 percent correctly predicted that the number of moles of CO would decrease under these conditions, only 27 percent realized that the concentration of CO would increase because of the volume being halved.

TABLE XVIII

Summary of Statistics of MIT Subtests

	Misconception Subtest					
	1	2	3	4	5	6
	(4)	(5)	(5)	(5)	(4)	(7)
Mean	2.6	3.2	2.5	0.7	1.2	3.3
S.D.	0.8	1.0	1.5	0.7	0.9	1.5

*Number in parentheses indicates number of items on subtest.

TABLE XIX

Intercorrelation of MIT Subtests

Misconception Subtest	Misconception Subtest 1	2	3	4	5	6
1	1.00					
2	$.21^{x}$	1.00				
3	.16	$.28^{xx}$	1.00			
4	-.11	-.14	-.02	1.00		
5	.08	.13	.12	.04	1.00	
6	.05	.11	.13	-.09	.15	1.00

x = $p < .05$

xx = $p < .01$

Forty-nine percent predicted that the concentration would decrease, presumably because the mass of CO also decreased. Students tend to associate any increase in mass with a corresponding increase in concentration and fail to appreciate other factors, like volume, which affect this relationship. This may well indicate that these students fail to integrate fully the two forms of reversibility (negation and reciprocity). This finding is reinforced by the results of asking the students to predict the effect on the mass and concentration of $COCl_2$ in the same system under the same conditions.

Here, again, a large number of students (70%) correctly predicted that the mass of $COCl_2$ would increase. An even larger number (83%) correctly predicted that the concentration of the $COCl_2$ would likewise increase. The fact that misconception 1 was found to be significantly related to cognitive level for the sample suggests that the students' inability to deal adequately with the INRC group transformations may be an underlying cause of the misconception.

The MIT included a section which required the student to state his reasoning in arriving at a particular response for five randomly selected items on the MIT. Analysis of this section was used to classify the type of misconception that occurred (Type I, Type II, Type III), discussed in a later section. In addition insight into the students' responses was gained by investigating their stated reasoning for particular items.

For example, in the above instance in which the student was asked to predict the effect on the equilibrium concentration of the CO as a result of decreasing the volume of the system, only 6 of the

17 students sampled on this item gave the correct answer. Of the students responding incorrectly the nature of the stated reasoning used in arriving at their answer strongly suggests a confusion between mass and concentration. Typical reasons stated included:

> . . . if there are less moles of CO then the concentration will be less.
>
> . . . the concentration does not change.
>
> . . . a concentration has shifted to the right to relieve pressure.
>
> . . . the concentration of the CO will be less in order for the $K_{eq.}$ valve to remain the same.

Misconception 2. *Rate vs. Extent*

This misconception deals with the confusion that arises between how fast a reaction proceeds (rate) and how far (extent) the reaction goes. It is possible to give examples of reactions that proceed very slowly in terms of completion but go almost to completion, and conversely, one can find instances of reactions (mainly in aqueous solutions) that proceed very rapidly but not to any degree of completion. Results of the MIT subtest dealing with this misconception suggest that students tend to associate rate with extent and vice versa. That is, given a system in which a larger amount of product is found as a consequence of some change on the system, a large percentage of students predicted this will result in a faster rate of reaction, even in those reactions which took place at a lower temperature.

Items 1 and 2 on the MIT illustrate the rate-extent misconception clearly. These items ask the student to predict the effect of lowering the temperature on the $COCl_2$ system. Although 43 percent were able to correctly predict that the equilibrium mass of $COCl_2$ increased, 21 percent predicted that the rate at which the $COCl_2$ is being formed was likewise increased, even at the lower temperatures. Analysis of the reasoning used by those students who predicted an increase in the rate of reaction suggests that any increase in the extent of the reaction implies an increase in the rate of the reaction. For example one student stated:

> . . . the reaction is shifted to the right, therefore the forward rate of reaction is increased.

Other reasons given included:

> . . . it [rate increase] has to be because more $COCl_2$ is being produced.

> . . . decrease in temperature favors products and therefore more $COCl_2$ is produced more quickly to overcome stress.

It might be noted here that all of the students who correctly predicted the greater rate of reaction on this item also indicated that their response was based on Le Chatelier's Principle. This suggests that misconception 2 may be related to misconception 4, that of the misuse of Le Chatelier's Principle. It is the opinion of the investigator that the six major misconceptions studied do vary in their order of importance for the understanding of chemical equilibrium. Misconceptions 1 and 2 are considered to be more specific in nature. They were found to occur to the same extent and to be significantly correlated ($p < .05$) to each other. Both misconceptions 1 and 2 were found to be significantly related to cognitive level.

Misconception 3. *'Constancy' of the Equilibrium Constant*

The five item subtest of the MIT dealing with this misconception revealed a considerable amount of uncertainty about the 'constancy' of the equilibrium constant. Generally students failed to appreciate that the numerical value of the equilibrium constant is dependent upon temperature alone.

Only one item (item 3) of the MIT required students to predict the change in the equilibrium constant as a result of an actual change in temperature. The four other items (9, 14, 19, and 29) all dealt with an equilibrium system at constant temperature and therefore a fixed equilibrium constant. In all cases well over 50 percent of the students responded incorrectly to these items.

The student reasoning sampled for these items incorrectly answered clearly indicated that the students tend to associate a change in the concentration of any reactant or product in the system with a change in the equilibrium constant, even though the temperature is held constant. Several of the reasons sampled for the items of the subtest associated with misconception 3 held that the equilibrium constant must change in numerical value if a new position of equilibrium is established at a constant temperature. Students do not appreciate that the equilibrium 'constant' is independent of the volume, the pressure, the presence of inert gases or additional equilibria, the direction from which equilibrium is approached and the initial concentration of the reacting species. The uncertainty of the nature of the equilibrium constant is evidenced by the following reasoning:

> . . . if you decrease the product and increase the reactant the result will be a smaller Keq. (constant temp).

> . . . the Keq would be less because the concentration of the $COCl_2$ would be lower (constant temperature).

Sixty-five percent of the students who missed the items associated with misconception 3 stated they were using Le Chatelier's Principle in their reasoning. Almost three-quarters of the remaining students indicated they used the Equilibrium Law in their reasoning. Clearly limitations of both Le Chatelier's Principle and the Equilibrium Law are not fully realized by these students.

Misconception 4. *Misuse of Le Chatelier's Principle*

Misconception 4 was found to be the most prevalent among the six misconceptions studied. This misconception refers to the excessive tendency of students to use what is termed 'Le Chatelier-type' reasoning in equilibrium problems which require a quantitative approach. The five item misconception 4 subtest had the lowest mean score (0.7) of the six subtests of the MIT.

The limitations of this extremely useful Principle in chemistry are clearly not understood by the majority of students. Items 15 and 16 serve to illustrate this misconception. Here students were asked to predict the equilibrium value on the number of moles of CO in the $COCl_2$ system as a consequence of adding a definite number of moles of $COCl_2$ and Cl_2 to the original equilibrium system. Although initial concentrations were not supplied to the student, 75 percent of the students predicted an increase in the number of moles of CO in item 15 and 70 percent predicted a decrease in item 16. Of the students sampled in the reasoning over 90 percent used Le Chatelier's Principle to arrive at their response. Little regard was given to the fact that there was insufficient information supplied to accurately predict the effect. The solution to these items requires a quantitative approach using the Equilibrium Law. The reasoning sampled for items on the misconception 4 subtest indicate that students generally apply a more intuitive, qualitative approach to equilibrium problems requiring more rigorous solutions.

The fact that the misconception 4 subtest items proved to be the most difficult for the students together with the finding that misconception 4 was the most prevalent suggests some basis for concern in this area. It may well be that the present CHEM Study text does not adequately indicate the limitations of Le Chatelier's Principle or difficulties involved in its use. This can be dangerous when students try to apply the principle to situations apparently similar to situations which are known to yield the correct answer, only to find they obtain the wrong answer.

Misconception 5. *Constant Concentration*

Misconception 5 refers to the inability of the student to appreciate that certain substances possess a fixed or constant concentration in certain chemical reactions. Investigation of the four item misconception subtest of the MIT dealing with this misconception revealed that considerable confusion is associated with the term 'constant concentration.'

Misconception 5 was found to be the second most prevalent misconception, being held by 84 percent of the study sample. Generally students felt that the mass of a substance which is said to have constant concentration affects the position of equilibrium established by a system.

Although the misconception over constant concentration is usually associated with ionic solutions in equilibrium (as in item 26), it was found to be equally prevalent in equilibrium problems dealing with homogeneous gaseous reactions (as in item 30).

In item 26 students were asked to predict the effect on the original equilibrium of removing half of the mass of an excess solid (silver chromate) in equilibrium with its aqueous ions. Here the concentration of the solid is said to be constant. Only 42 percent of the students correctly predicted that the removal of some of the solid would not affect the established equilibrium. A greater proportion (45%) felt that the position of equilibrium would be changed. The reasons stated by those students who held this misconception strongly reflect the feeling that the removal of any substance in a system at equilibrium must result in a change in the position of equilibrium. Here again Le Chatelier reasoning was used to arrive at their responses.

Although item 30 dealt with a homogeneous gaseous reaction in which the substance displaying constant concentration was liquid water, the results were similar to those of item 26. Little account was given to the role of the liquid water in the system as 60 percent of the students felt that the amount of mass of water present affected the established equilibrium.

The relatively low mean (1.2) for the 4 item subtest dealing with misconception 5 indicates the degree of difficulty students have in dealing with equilibrium problems involving substance of constant concentration.

Misconception 6. *Competing Equilibria*

Misconception 6 refers to the inability of students to take into consideration all possible factors that may affect the equilibrium condition of a chemical system. It was found to be the third most prevalent misconception studied, being held by 60 percent of the sample. The seven item subtest dealing with misconception 6 had a mean score of 3.3.

In examples where there are 'competing equilibria' or where there are two or more 'opposing effects' to be considered, students had considerable difficulty in dealing with all factors affecting the equilibrium condition. For example, in item 22 students were asked to predict the effect of the addition of acid to an existing acid equilibrium system. Both acids compete in their dissociation to form a common ion (H_3O^+). To correctly predict the effect of the addition of the acid, students must consider 1) the dissociation of the acid, and 2) its effect on the original system. Evidence that the relevant factors were not always considered is given by the results for this item. Twenty-three percent of the sample indicated the additional acid would have no effect on the system. The reasons sampled for students possessing misconception 6 indicated that although Le Chatelier's Principle was generally used to arrive at their answers, it was applied in a limited manner, often neglecting important factors. As the inability to take into consideration all possible factors in a problem-solving situation is a basic characteristic of concrete operational thought, this suggests a relationship may exist between misconception 6 and cognitive level. However, the chi square test of independence between misconception 6 and level of cognitive functioning as measured by PT 1 proved nonsignificant ($\chi^2 = 1.5$, $.20 < p < .30$).

Types of Misconception

The addition of the reasoning section to the MIT enabled one to classify the possessed misconception into one of three main types. That is, sampling the reasons stated for choosing particular responses to the MIT items provided some insight into the nature of the misconception. Misconceptions were classified as follows:

Type I Misconception. Here the answer given is correct but the reasoning is incorrect or irrelevant to the item. Type I misconceptions were found to be the least prevalent of the three misconception types identified, occurring in only 10 percent of the items sampled on the MIT reasoning section. Generally if the student's response was correct the stated reason was also correct. An example of a Type I misconception is given by a student's answer to item 26, in which the student correctly predicted that the removal of half of the solid from the system will have no effect on the original equilibrium system. However, the stated reason given that the solid has limited solubility is incorrect.

Type II Misconception. This refers to the situation where, although the given asnwer is incorrect, the answer stated is correct, as far as it goes. Type II misconceptions were found to occur in approximately 25 percent of the items for which reasons were given. Often the reason stated was too limited or incomplete and was possibly a major factor in the student's incorrect response. For example, in items dealing with misconception 3, the constancy of the equilibrium constant, a frequent reason given was that the equilibrium constant is a constant. Although this reason is correct under constant temperature conditions it is too limited to correctly answer the relevant items.

Other examples of the occurrence of Type II misconceptions suggest that it is related to misconception 4, that of the misuse of Le Chatelier's Principle. The fact that misconception 4 was found to be extremely prevalent might account for the relatively large number of Type II misconceptions found. That is, the tendency of many students to misuse or to apply Le Chatelier's Principle in only a limited measure may give rise to Type II misconceptions.

Type III Misconceptions. A Type III misconception is said to exist if both the answer and stated reason for an item on the MIT are incorrect. This type of misconception was the most frequently occurring of the three types studied and proved the easiest to identify. Often the reasoning given was both incorrect and irrelevant. Unfortunately in the case of a Type III misconception it is difficult to gain much insight into the reasons for the obvious misunderstanding the student possesses. However, one suspects that a weak background or lack of mastery of certain essential prerequisite areas in chemistry (e.g., reaction rates, kinetic molecular theory) may be a major cause of Type III misconceptions. A sound review of basic concepts underlying chemical equilibrium should reduce the occurrence of Type III misconceptions.

CHAPTER V

SUMMARY, DISCUSSION AND RECOMMENDATIONS

Introduction

In this final chapter, a summary of the purpose and design of the study, together with its findings, is presented. Several recommendations for the classroom teaching of chemical equilibrium are presented. Finally some considerations for further study are outlined.

Summary

The purpose of the present study was to ascertain the relationship between selected student misconceptions in the area of chemical equilibrium and performance on specific tasks involving cognitive transformations characteristic of the concrete and formal cognitive levels of thought.

The study was conducted in two large Edmonton senior high schools on a sample of 99 students enrolled in four chemistry 30X classes during the 1973 spring semester.

Four main test instruments were administered. The Misconception Identification Test (MIT) was developed specifically for the study in order to identify specific misconceptions in the area of chemical equilibrium and to determine the extent to which they occurred. The six subtests contained within the MIT deal with the following six misconceptions: (1) mass vs. concentration, (2) rate vs. extent of reaction, (3) constant concentration, (4) misuse of Le Chatelier's Principle, (5) the constancy of the equilibrium 'constant' and

(6) competing equilibria. Students were asked on the MIT to predict the effect of various variables on the equilibrium conditions of several chemical reactions. In addition, students were asked to state their reasoning for their predictions for five randomly chosen items on the MIT.

The Chemistry Achievement Test (CHAT), based on Chapters 7, 8, 9, and 10 of the CHEM Study text, was used as a measure of achievement in chemistry. The Piagetian Tasks (PT 1 and PT 2, SK6) formed the basis for the categorization of the student sample (N=99) into the respective level and substage of concrete and formal thought. PT 1 and PT 2 were combinatorial tasks which involved the investigation of the nature of five colorless chemical solutions by manipulation of the various combinations of the solutions. The Skemp Test (SK6) consisted of three 15 item sections based on ten operations involving the four transformations of the INRC physical group model. The grade nine Co-operative School and College Ability Test (SCAT) scores were also obtained for the sample.

Revisions and certain administrative changes associated with the MIT and the Piagetian Tasks (PT 1 and PT 2) were made on the basis of a pilot study conducted on 62 students in three separate chemistry 30X classes prior to the formal administration of the test instruments to the study sample.

The CHAT was administered first, followed by the MIT during the regular class period the next day. The Piagetian Tasks (PT 1 and PT 2 and SK6) were administered approximately one week later. All test administration was carried out by the investigator. Both the CHAT and the MIT scores were used by the three cooperating teachers in their regular evaluation of the chemistry course.

Evaluation of the students' performance on the Piagetian tasks (PT 1 and PT 2) was made on the basis of specified criteria as outlined by Inhelder and Piaget (1958), and in consultation with Piagetian experts. Performance on the SK6 was used as a measure of the students' perception of the INRC group.

The Misconception Identification Test was scored according to two separate and distinct keys, designated MIT(A) and MIT(B). MIT(A) refers to the keying of the MIT accurately in the chemical sense, while MIT(B) refers to the scoring of the MIT according to the six major misconceptions identified by the instrument. In this manner, performance scores (MIT[A]) and misconceptions scores (MIT[B]) were obtained for each student for each of the major misconceptions. Categorization as to the presence or absence of each misconception was made on the basis of both the performance and misconception scores for each student.

Item analysis of the MIT revealed that the probability of students choosing the keyed misconception response for each of the 30 items on the test consistently exceeded that expected by chance alone. Chi square values for 25 of the item response distributions proved significant ($p < .01$). Analysis of the performance and misconception scores indicated that 82 percent of the sample possessed three or more of the six misconceptions identified.

The correlations between the CHAT scores and the scores of the Piagetian tasks, PT1, SK6(1), SK6(2), and SK6(3), were all found to be significant at the 0.05 level. A stepwise regression analysis carried out for the prediction of achievement in chemistry revealed that PT 1 and SK6(2) were both significantly contributing predictor variables and were able, together, to account for 58.7 percent of the variance of the CHAT scores. Neither the verbal SCAT score nor the quantitative SCAT score contributed significantly to the prediction. The low predictive value associated with the grade nine SCAT scores was not altogether unexpected in view of the three year time interval that elapsed since the administration of these tests.

In terms of levels of cognitive functioning, the 99 students in the study sample were classified as: early concrete (C_1), 3 students; late concrete (C_2), 24 students; early formal (F_1), 61 students, and late formal (F_2), 11 students. In gross terms, 73 percent were found to be capable of using formal operations in their thinking, while 27 percent were limited to concrete operations with respect to the two equivalent Piagetian tasks (PT 1 and PT 2) used in this study.

The sample was divided into three nearly equal achievement groups (high, middle and low) according to performance on the CHAT. One-way analysis of variance was carried out on the scores of the three achievement groups on the following measures: MIT(A), MIT(B), SK6(1), SK6(2), SK6(3), PT 1, SCAT Verbal and SCAT Quantitative. Results revealed that, with the exception of the two sections of the Skemp test (SK6[1] and SK6[3]), the three achievement groups were significantly different with respect to each of the above measures. This was seen as a measure of the validity of these instruments as used in the study.

The correlations between the two forms of the MIT, MIT(A) and MIT(B), and the Piagetian tasks, PT 1 and SK6, were all significant at the .01 level, suggesting that there is a significant relationship between the number of misconceptions possessed by students and performance on the selected Piagetian tasks. This finding is supported by the significant relationship found between the number of possessed misconceptions and the cognitive level of the students, as determined by PT 1.

The chi square test of independence performed between each of the six misconceptions identified and the cognitive level of the sample revealed that two of the misconceptions, namely the misconceptions dealing with mass vs. concentration and rate vs. extent of reaction, were significantly related to the cognitive level as measured by PT 1.

A stepwise regression analysis performed on the prediction of MIT(B) scores found the CHAT score to be the only significantly contributing predictor variable ($p < .001$). This finding, together with the significant ($p << .001$) correlation between MIT(B) and CHAT, suggests that the number of misconceptions possessed by students in the area of chemical equilibrium is related to achievement in chemistry. Further, three of the six specific misconceptions investigated were also found to be significantly related to achievement in chemistry.

No significant sex difference was observed for either the total number of misconceptions held by students in this area or any of the specific misconceptions investigated. No significant relationship between either the number of misconceptions held or specific misconceptions held and mathematical ability, as measured by the quantitative section of the grade nine SCAT score, was found.

Recommendations

Recommendations for Classroom Teaching

The relationship between the nature and extent of misconceptualization and cognitive level of development suggests numerous implications for the high school chemistry teacher. Findings in the present study would suggest that before introducing the principle of chemical equilibrium formally, some assessment of each student's cognitive level be attempted. The measures used to determine the cognitive level of the subjects in this study (PT 1 and SK6) are appropriate to the context of a chemistry class and might be given beforehand with relatively little difficulty. For example, PT 1 could serve as a relevant introductory laboratory exercise in chemistry 30. This would both allow an early assessment of each student's cognitive level and provide an opportunity to discuss the basic chemical reactions involved in the various combinations of the solutions in the task. This approach would seem to lend itself well to a review of the writing and balancing of equations, stoichiometry, oxidation and reduction, etc., which many chemistry teachers find necessary.

Information as to the students' level of cognitive development might well result in a more efficient and rapid review of concepts basic to the understanding of chemical equilibrium. That is, those students operating at the early or late concrete levels may benefit more from a laboratory approach involving *concrete* situations in which they can observe the effect of varying certain variables on a chemical system at equilibrium. The concept of mass, concentration, rate of reactions and extent of reaction seem particularly critical to a sound understanding of equilibrium. Exercises and programmed materials dealing with these concepts at both the concrete and formal levels could be prepared to allow a student to enter the review sequence at his appropriate level.

Further, a knowledge of the major misconceptions identified in the present study should prove useful to the classroom teacher in devising instructional strategies to alleviate or minimize each of these misunderstandings. The limitations contained in Le Chatelier's Principle, for example, might be more clearly illustrated by the use of several well chosen problems not contained in the CHEM Study text. Problems to which Le Chatelier type reasoning is not amenable should also be presented and discussed with the students. The relatively few problems on chemical equilibrium contained in the CHEM Study text are qualitative in nature and easily resolved by the Le Chatelier Principle. The high prevalence of the misuse of Le Chatelier's Principle in the present study can be easily understood if students were in the practice of applying the Principle only to examples where it was previously known to give a correct answer. Rather than adopt the CHEM Study 'approach' to equilibrium, as many examples of equilibria as possible, both qualitative and quantitative, should be made available to the students.

Graphical representations used in conjunction with the teaching of the concepts of constant concentration and the 'equilibrium constant' may prove useful to the chemistry teacher in overcoming misunderstandings so often associated with these concepts. For example, concentration vs. time graphs could be introduced to illustrate the effect of introducing more reactant or product into a system at equilibrium. Plotting the change in concentration over time may help some students to more concretely visualize what actually happens in the process. Similarly, the effect of the addition of a catalyst could be explained by the use of rate vs. time graphs.

Recommendations for Further Research

As a result of this investigation, the following research possibilities are suggested:

1. The present study could be replicated in other areas and levels of science teaching. Modifications in the testing procedure could be carried out in order to study misconceptions related to other topics at the high school level, e.g., misunderstanding in kinetic molecular theory. The approach used in this study also seems amenable to identifying misconceptions related to specific areas of science that may occur among elementary and junior high school science students.
2. The effect that various instructional strategies have on the elimination or minimization of the misconceptions identified in the present study should be investigated. Specific instructional techniques might be devised and their outcomes on the incidence of these misconceptions and student achievement in this area examined.
3. The effect of revising the present curriculum approach to chemical equilibrium upon the degree of misconceptualization could be investigated. Considerations could include:
    a) re-ordering the topics dealt with in equilibrium, e.g., solubility equilibria could precede the section on homogeneous gaseous reactions.
    b) placing more emphasis on the quantitative treatment of chemical equilibria.

c) introducing several short laboratory exercises designed to illustrate basic concepts in equilibrium commonly misunderstood.

4. The effect of teaching chemical equilibrium at varying levels of cognitive development could be undertaken. This may indicate the optimum level of abstraction that should be given to the topic.
5. A more definitive study of the role of the INRC physical group model in relation to misconceptions involving chemical and mechanical equilibria seems indicated. Problems in equilibrium would have to be analyzed rigorously in relation to the INRC transformations and instruments devised to measure students' performance in applying these transformations.
6. Refinements could be made to the Misconception Identification Test to identify further misconceptions in chemical equilibrium and the relationships that may exist among them. For example, misunderstandings over the 'dynamic' nature of chemical equilibrium, uncertainty over what constitutes an equilibrium situation, and the effect of a catalyst.
7. The predictive value of instruments like the Piagetian Tasks (PT 1 and SK6) used in the present study could be investigated more fully. Tasks of this nature could be used as diagnostic tools in other areas of science learning.

FOOTNOTES

[1] Inhelder, Barbel and Jean Piaget, *The Growth of Logical Thinking from Childhood to Adolescence*, Basic Books, New York, 1958, p. 107-122.

[2] Source of definition: *Handbook of Chemistry and Physics*, 49th ed., 1968-1969. Robert C. Weast (Ed.), The Chemical Rubber Co., Cleveland, Ohio, 1968.

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APPENDICES

APPENDIX A

THE MISCONCEPTION IDENTIFICATION TEST (MIT)

CHEMICAL EQUILIBRIUM

This is an OPEN-BOOK examination. Answer each question by indicating on the answer sheet provided the most appropriate of the following responses:

A. GREATER THAN that at the first equilibrium.

B. LESS THAN that at the first equilibrium.

C. THE SAME AS that at the first equilibrium.

D. There is INSUFFICIENT information provided to decide among the above alternatives.

Use a HB pencil to fill in the corresponding space on the answer sheet. You have 60 minutes to complete the test.

In addition, for those questions mentioned on the separate sheet indicate by means of a brief statement, your reason(s) for selecting the response.

Place your reason(s) in the spaces provided on the separate sheet.

DO NOT WRITE ON THE QUESTION BOOKLET.

Example question

Consider an equilibrium mixture of nitrogen, hydrogen and ammonia (all in the gaseous state) at 500°C and 200 atmospheres pressure. The balanced equation for the reaction is:

$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$, the forward reaction being endothermic (i.e. taking place with the absorption of heat).

More N_2(g) is added to the equilibrium mixture, keeping the volume and the temperature constant. When the system returns to equilibrium, the number of moles of NH_3(g) will be. . . . .

In each one of questions 1-20, you are asked to consider an equilibrium mixture of CO, Cl_2, and $COCl_2$ (all of which are gases) initially at $200^{\circ}C$ and 1 atmosphere pressure.

The balanced equation is given by:

$CO(g) + Cl_2(g) \rightleftharpoons COCl_2(g)$, the forward reaction being exothermic (i.e. taking place with the evolution of heat).

When answering the question, do not assume any knowledge of this particular chemical system other than that provided by the above information or in the questions asked.

QUESTIONS 1-3 refer to the following change made on the above reaction:

The mixture is cooled to $150^{\circ}C$ (at which temperature all three substances are still completely in the gaseous state), keeping the volume constant.

When the system returns to equilibrium:

1. the number of moles of $COCl_2$ present will be. . . . . (place answer on answer sheet)
2. the rate at which $COCl_2$ is being formed will be. . .
3. the equilibrium value of $\dfrac{[COCl_2]}{[CO]\,[Cl_2]}$ will be . . . .

QUESTIONS 4-7 refer only to the following change made on the original reaction.

The volume of the system is halved by increasing the pressure at constant temperature. When the system has returned to equilibrium:

4. the number of moles of $COCl_2$ present will be . . . .

5. the concentration (or partial pressure) of $COCl_2$ present will be. . . . .

6. the number of moles of CO present will be. . . . .

7. the concentration or partial pressure of CO present will be. . .

$$CO(g) + Cl_2 \rightleftharpoons COCl_2(g) + \text{heat}$$

QUESTIONS 8-10 refer only to the following change made on the original reaction.

Some Cl_2 is removed from the system, the volume and temperature being held constant. When the system has returned to equilibrium:

8. the number of moles of CO present will be. . . . .

9. the equilibrium value of $\frac{[COCl_2]}{[CO]\,[Cl_2]}$ will be. . . . .

10. the rate at which CO is being formed will be. . . . . . .

QUESTION 11 refers only to the following change made on the original reaction:

Some inert gas (say, Neon) is added to the system, keeping the volume and the temperature constant. When the system has returned to equilibrium:

11. the number of moles of $COCl_2$ present will be. . . . .

QUESTIONS 12-14 refer only to the following change on the original reaction.

-p 3-

Some neon is added to the system, this time keeping the total pressure and temperature constant. When the system has returned to equilibrium:

12. the number of moles of $COCl_2$ will be. . . . .

13. the concentration or partial pressure of Cl_2 will be. . . . . .

14. the equilibrium value of $\frac{[COCl_2]}{[CO][Cl_2]}$ will be. . . . .

In QUESTION 15, consider only the following change made on the original reaction:

15. One mole of $COCl_2$ and 0.01 mole of Cl_2 is added at constant volume and temperature. When the system has returned to equilibrium, the number of moles of CO will be. . . . .

$$CO(g) + Cl_2(g) \rightleftarrows COCl_2(g) + heat$$

In QUESTION 16, the following change is made on the original reaction:

16. this time, 0.01 mole of $COCl_2$ and 1 mole of Cl_2 is added at constant volume and temperature. When the system has returned to equilibrium, the number of moles of CO will be. . . . .

QUESTIONS 17-19 refer to the following addition to the original reaction:

A certain amount of nitric oxide, NO, is introduced into the system at constant volume and temperature. NO also reacts with Cl_2, according to the following equation: $NO(g) + Cl_2(g) \rightleftarrows NOCl_2(g)$

When the system has returned to equilibrium:

17. the number of moles of CO will be. . . . .

18. the concentration or partial pressure of the $COCl_2$ will be. . . .

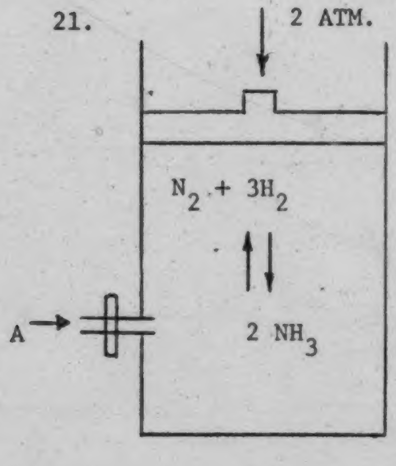
19. the equilibrium value of $\frac{[COCl_2]}{[CO]\,[Cl_2]}$ will be. . . . .

QUESTION 20 refers again to the original reaction in which:

20. Some Cl_2 is added to the system at constant volume and temperature.

When the system has returned to equilibrium, the concentration or partial pressure of the CO will be. . . . .

THE REMAINING QUESTIONS REFER TO PARTICULAR REACTIONS AS DESCRIBED IN THE GIVEN QUESTIONS AND NOT THE SYSTEM USED IN THE ABOVE QUESTIONS.



21. Consider a cylinder (see diagram) containing a gaseous equilibrium mixture of N_2, H_2, and NH_3 under a constant pressure of 2 atmospheres and kept at constant temperature. Through a valve, A, in the side of the cylinder more $N_2(g)$ is added (the total pressure and the temperature both being

constant). When equilibrium has again been attained, the number of moles of NH_3 present will be. . . . . .

22. Formic acid, HCOOH, is a weak organic acid and as such partially dissociates in aqueous solution according to the following equation:

$$HCOOH + H_2O \rightleftharpoons H_3O^+(aq.) + HCOO^-(aq.)$$

To a 0.1 M solution of formic acid is added a small amount of concentrated hydrochloric acid which dissociates as follows:

$$HCl + H_2O \rightleftharpoons H_3O^+(aq.) + Cl^-(aq.)$$

When the system has returned to equilibrium, the molarity of formate ions, $HCOO^-$ will be. . . . .

QUESTIONS 23-25

One litre of 0.1 M formic acid solution (actually an equilibrium mixture of formic acid molecules, hydrogen ions and formate ions as described in Q. 22) is diluted to 10 litres with distilled water. When the mixture has returned to equilibrium:

23. the number of formate ions will be. . . . . .

24. the molarity of the formate ions will be. . . . .

25. the dissociation of formic acid into hydrogen ions and formate ions is an endothermic process. Heat is absorbed. If 0.1 M formic acid at 25°C is heated to 30°C, the fraction of formic acid molecules dissociated, at equilibrium, will be. . . . . .

26. A vessel contains an aqueous solution of Ag^+ ions and CrO_4^{-2} ions in equilibrium with solid Ag_2CrO_4.

$$2Ag^+(aq.) + CrO_{4(aq.)}^{-2} \rightleftharpoons Ag_2CrO_4(s)$$

Half of the solid Ag_2CrO_4 present is now removed. Analysis of the solution after many hours would indicate that the molarity of $Ag^+(aq.)$ is now. . . . .

27. Some finely divided metallic silver is added to a litre of 0.1 M ferric chloride acidified with HCl, and the following equilibrium is set up:

$$Fe^{+3}(aq.) + Ag(s) \rightleftharpoons Fe^{+2}(aq.) + Ag^+(aq.)$$

Assume that this is the only equilibrium established.
This equilibrium mixture is diluted to 10 litres with distilled water. When equilibrium is again attained, the number of moles of metallic silver present will be. . . . . . .

QUESTIONS 28-29 refer to the following reaction:
Consider an equilibrium mixture between ferric ions (Fe^{+3}) and thiocyanate ions (SCN^-) at a constant temperature as given by the equation:

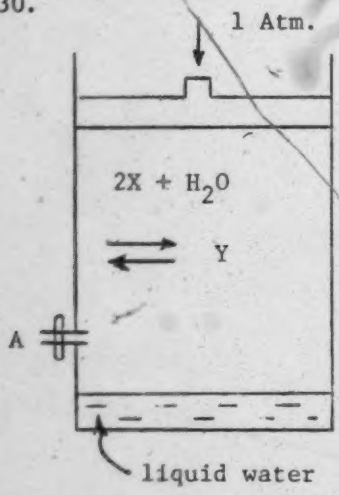
$$Fe^{+3}(aq.) + SCN^-(aq.) \rightleftharpoons FeSCN^{++}(aq.)$$

To this equilibrium mixture is added some finely divided silver and an equilibrium is established between the $Fe^{+3}(aq.)$ and Ag(s) as described in Question 27 above.
When equilibrium is again established:

28. the number of thiocyanate ions (SCN^-) will be. . . . . . .

29. the equilibrium value of $\frac{[FeSCN^{++}]}{[Fe^{+3}][SCN^{-}]}$ will be. . . . .

30.



Consider a cylinder (see diagram) containing an equilibrium mixture of X, Y and H_2O which react according to the equation: $2X + H_2O \rightleftharpoons Y$, under a constant pressure of one atmosphere. In the cylinder there is gaseous X, Y and H_2O, together with some liquid water. (In which X and Y are Quite insoluble).

Water vapor is added to the cylinder through a side valve, A. When the system returns to equilibrium, the number of moles of Y will be . . . .

CHEMICAL EQUILIBRIUM Name______________

School______________

Date______________

For each of questions indicate by means of a brief statement, your reason(s) for selecting your response. Place your reason(s) in the space provided. In addition indicate which law or principle you used in your reasoning. i.e.

X if you used the Equilibrium Law

Y if you used Le Chatelier's Principle

Z if you used some other law or principle.

QUESTION Circle one: Answer A B C D, X Y Z

QUESTION Circle one: Answer A B C D, X Y Z

QUESTION Circle one: Answer A B C D, X Y Z

QUESTION Circle one: Answer A B C D, X Y Z

QUESTION Circle one: Answer A B C D, X Y Z

APPENDIX B

THE CHEMISTRY ACHIEVEMENT TEST (CHAT)

CHEMISTRY 30X ACHIEVEMENT TEST -- Chapters 7, 8, 9 and 10

This is an open book test which you have 60 minutes to write. Select the best answer for each question.

Use an HB pencil to fill in the corresponding space on the answer sheet.

1. When concentrated sulfuric acid is added to water, heat is liberated. The heat of dilution is about 18 kcal/mole of H_2SO_4 diluted with a large volume of water. If 9.8 g of H_2SO_4 were added to 10.0 litres of water, what would be the increase in the temperature of the water?

   A. 18C°
   B. 1.8C°
   C. 0.98C°
   D. 0.18C°
   E. 0.018C°

2. When 8.00 g of CH_4 are burned to produce carbon dioxide and water vapor, 104 kcal of heat are released. What is the ΔH value for the following reaction?

   $$CH_{4(g)} + 2O_{2(g)} \rightleftharpoons CO_{2(g)} + 2H_2O_{(g)}$$

   A. +208 kcal
   B. +104 kcal
   C. -94.0 kcal
   D. -104 kcal
   E. -208 kcal

3. Calculate the heat of combustion in kcal/mole of H_2S. Use the equations and data given below:

   $H_{2(g)} + S_{(s)} \rightleftharpoons H_2S_{(g)}$ $\Delta H = -9.6$ kcal

   $H_{2(g)} + \frac{1}{2}O_{2(g)} \rightleftharpoons H_2O_{(g)}$ $\Delta H = -57.8$ kcal

$S_{(s)} + O_{2(g)} \rightleftharpoons SO_{2(g)}$ $\Delta H = -71.0$ kcal

$H_2S_{(g)} + 3/2O_{2(g)} \rightleftharpoons H_2O_{(g)} + SO_{2(g)}$ $\Delta H = ...$

A. 138.4 kcal/mole
B. -3.6 kcal/mole
C. -9.6 kcal/mole
D. -119.2 kcal/mole
E. -138.4 kcal/mole

Questions 4 to 6 refer to the following reactions, for which the heats of reaction are given.

Reaction 1. $K_{(s)} + \frac{1}{2}Cl_{2(l)} \rightleftharpoons KCl_{(s)}$ $\Delta H = -100.0$ kcal

Reaction 11. $K_{(s)} + \frac{1}{2}Cl_{2(g)} \rightleftharpoons KCl_{(s)}$ $\Delta H = -104.8$ kcal

4. Which of these statements regarding reaction 1 is FALSE?

A. The heat content of the produce, KCl, is less than that of the reactants.
B. If the reaction is carried out in a rigid, insulated container, the temperature in the container will rise.
C. The potential energy of the reactants is less than that of the products.
D. For each mole of $KCl_{(s)}$ formed, 100.0 kcal of heat is released.
E. The reaction is exothermic.

5. The value obtained by subtracting equation 11 from equation 1 (+4.8 kcal) represents:

A. the heat releaseddwhen 2.00 moles of $KCl_{(s)}$ form.
B. the heat required to melt 1.00 mole of $KCl_{(s)}$.
C. the heat required to vaporize 0.500 moles of $Cl_{2(l)}$.
D. the heat released when 0.500 moles of $Cl_{2(g)}$ condense.
E. probably due to errors in measurement.

6. The formation of 24.9 g of $KCl_{(s)}$ in reaction 11 is accompanied by the release of:

A. 4.8 kcal
B. 34.9 kcal
C. 100.0 kcal
D. 104.8 kcal
E. none of these

7. To complete the equation:

$$M + {}^{1}_{0}n \rightleftharpoons {}^{X}_{A}J + {}^{Y}_{Z}K + 2{}^{1}_{0}n$$

M would have to be written

A. ${}^{X+Y-1}_{A+Z}M$

B. ${}^{X+Y}_{A+Z}M$

C. ${}^{X+Y+1}_{A+Z}M$

D. ${}^{X+Y+1}_{A+Z+1}M$

E. ${}^{X+Y+2}_{A+Z}M$

8. If a sample of water were warmed from $0^{o}K$ to $2.0 \times 10^{7}\,{}^{o}K$, each of the following processes would be expected to occur at some time during the heating.

I. $H_2O_{(g)} \rightleftharpoons H_{(g)} + OH_{(g)}$

II. $H_2O_{(1)} \rightleftharpoons H_2O_{(g)}$

III. $H_2O_{(s)} \rightleftharpoons H_2O_{(1)}$

IV. ${}^{2}_{1}H + {}^{3}_{1}H \rightleftharpoons {}^{4}_{2}He + {}^{1}_{0}n$

As the temperature is raised, in what order would the processes tend to occur?

A. I, II, III, IV
B. II, III, I, IV
C. III, II, I, IV
D. III, II, IV, I
E. IV, III, II, I

9. Raising the temperature of a reacting system would

A. increase the rate of the forward reaction only.
B. increase the rates of both forward and reverse reactions.
C. increase the rate of the forward reaction and decrease the rate of the reverse reaction.
D. decrease the rates of both forward and reverse reactions.
E. decrease the rate of the forward reaction and increase the rate of the reverse reaction.

10. Among the factors which affect reaction rate are: concentration, collision geometry, and the presence of a catalyst. Which of the following statements is FALSE concerning these factors?

    A. Increasing the concentration of reacting particles increases the chance for collisions.
    B. Optimum collision geometry lowers the activation energy barrier.
    C. A catalyst lowers the activation energy requirement.
    D. The reaction occurs each time particles of the reactants collide.
    E. The slowest reaction involved in a reaction mechanism determines the rate of the overall reaction.

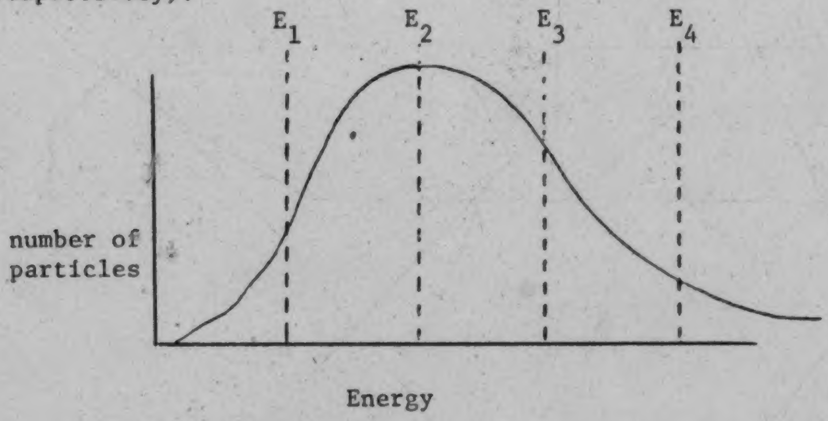
11. $NO_{(g)} + O_{2(g)} \rightleftharpoons NO_{3(g)}$ (fast) A

    $NO_{3(g)} + NO_{(g)} \rightleftharpoons 2NO_{2(g)}$ (slow) B

    Which of the following does the above pair of reactions best illustrate?

    A. entropy
    B. randomness
    C. catalysis
    D. activation energy
    E. reaction mechanism

Questions 12 to 14 are based on the following information. The kinetic energy distribution curve shown below applies to four different reactions all at the same temperature. Only the activation energy (E) is different. (The activation energies of reactions 1, 2, 3 and 4 are designated E_1, E_2, E_3, and E_4 respectively).



12. Under the same conditions, which reaction would occur the fastest?

    A. reaction 1
    B. reaction 2
    C. reaction 3
    D. reaction 4
    E. all reactions would occur at the same rate

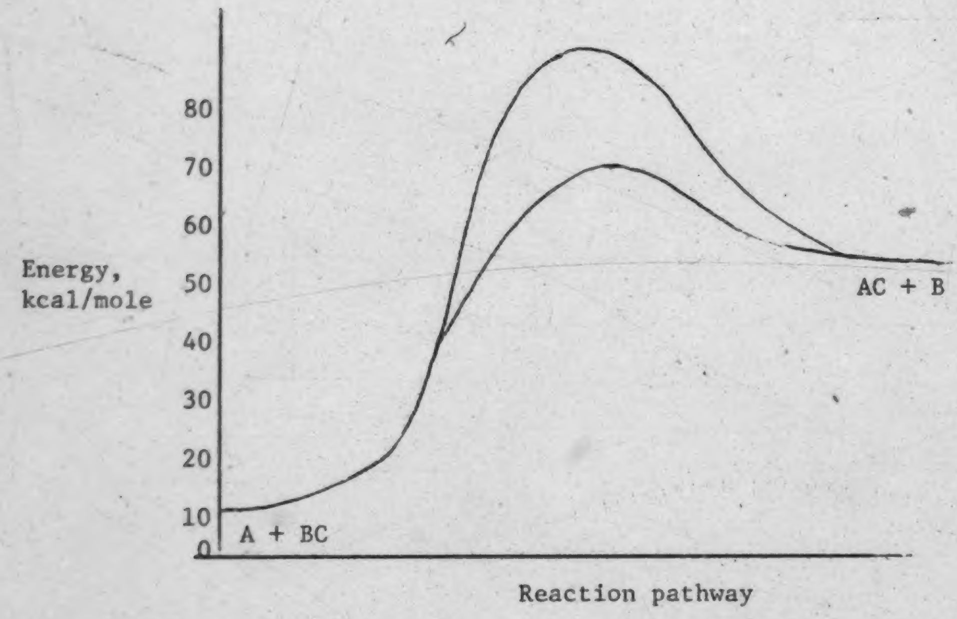
13. If a catalyst were added to reacting system 3, what effect, if any, would this have on the system?

    A. The peak of the kinetic energy distribution curve would be shifted to the left.
    B. The peak of the kinetic energy distribution curve would be shifted to the right.
    C. The activation energy requirement would be raised, so fewer molecules would collide successfully.
    D. The activation energy requirement would be lowered, so more successful molecular collisions would occur.
    E. There would be no effect on the system.

14. In which of the above systems would the reaction rate be increased most by heating the reactants?

    A. reaction 1
    B. reaction 2
    C. reaction 3
    D. reaction 4
    E. none of them would be affected

Questions 15 and 16 are based on the following diagram, which shows two pathways for a given reaction. One is for the uncatalyzed reaction, and one is for the catalyzed reaction.



15. The activation energy for the forward reaction, in the presence of a catalyst, is about

    A. 40 kcal/mole
    B. 50 kcal/mole
    C. 60 kcal/mole
    D. 70 kcal/mole
    E. 80 kcal/mole

16. In the uncatalyzed forward reaction the overall heat of reaction, H, is about

    A. -70 kcal/mole
    B. -50 kcal/mole
    C. -40 kcal/mole
    D. 40 kcal/mole
    E. 70 kcal/mole

17. The equilibrium state for any chemical reaction in a closed system results from a balance between:

    A. maximum energy and maximum randomness
    B. minimum energy and maximum randomness
    C. maximum energy and minimum randomness
    D. minimum energy and minimum properties
    E. constancy of macroscopic properties

18. The equilibrium of a chemical system of gases can NEVER be changed by

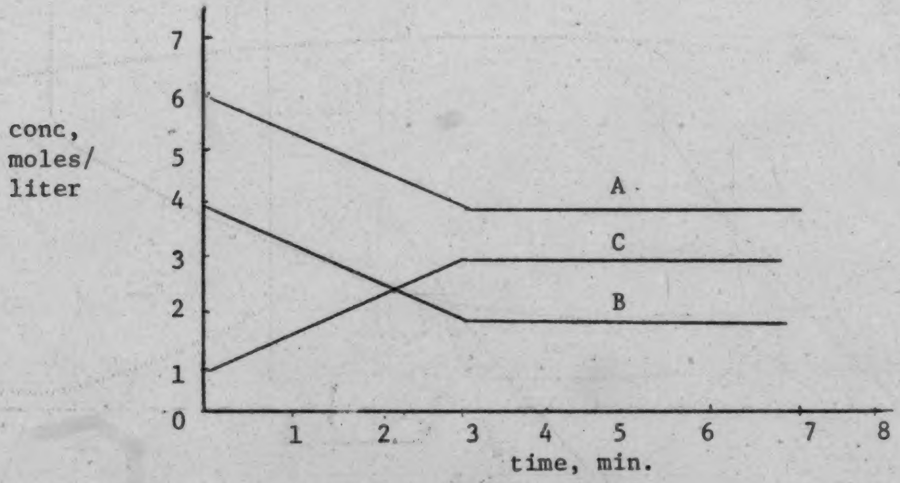
A. increasing the pressure
B. increasing the temperature
C. adding more of one reactant
D. adding more of one product
E. introducing a catalyst

19. Assume that the following reaction has reached equilibrium in a closed container, and that it is desired to obtain a greater yield of $SO_{3(g)}$ by shifting the equilibrium to the right. This may be accomplished by which one of the following changes?

$$S_{8(s)} + 12O_{2(g)} \rightleftharpoons 8SO_{3(g)} + 95.1 \text{ kcal}$$

A. Increase the pressure by compressing the system into a smaller volume.
B. Add a catalyst without changing the temperature or pressure.
C. Increase the temperature without changing the pressure.
D. Remove oxygen gas from the system.
E. Increase the randomness of equilibrium system by stirring it.

20. Chemicals A and B react according to the following graph.



The balanced equation for the reaction is
A. $2A + 2B \rightleftharpoons 2C$
B. $4A + 2B \rightleftharpoons 3C$
C. $6A + 4B \rightleftharpoons C$
D. $6A + 4B \rightleftharpoons 2C$
E. none of the above

Questions 21 to 23 concern a system in which $CrBr_3$ dissolves in alcohol. A single crystal of $CrBr_3$ is weighed and placed in Beaker A. An equal mass of small crystals is placed in beaker B. The beakers are vigorously stirred at room temperature, then covered.

21. The $CrBr_3$ in beaker A initially

    A. dissolves more rapidly than that in B
    B. dissolves more slowly than that in B
    C. dissolves at the same rate as that in B
    D. dissolves at a rate independent of temperature
    E. has more surface area than that in B

22. The equilibrium concentration of dissolved $CrBr_3$ in beaker B might be increased by

    A. crushing the crystals to powder
    B. more vigorous stirring
    C. warming the beaker and maintaining it at a higher temperature
    D. adding more alcohol
    E. adding more solid $CrBr_3$

23. After several hours, equilibrium is reached in both beakers. Beaker A still has a single crystal and beaker B still has many small ones. Which of the following statements about the systems at equilibrium is FALSE?

    A. Dissolving and crystallization of $CrBr_3$ are taking place in both beakers.
    B. Within each beaker the rate of dissolving equals the rate of crystallizing.
    C. The colour of the solution is constant in each beaker.
    D. More undissolved solid remains in A than in B.
    E. The amount of undissolved solid is not changing in either beaker.

24. The threshold energy in a reaction system would change in which of the following cases?

    I. the temperature is changed.
    II. the reactants are changed.
    III. the concentration of the reactants are changed.
    IV. a catalyst is introduced or removed.

    A. I, II, III AND IV
    B. I, II, III
    C. I AND II
    D. III AND IV
    E. none of the above

Questions 25 and 26 are based on the following information.

Gaseous water reacts with carbon monoxide gas to produce hydrogen gas and carbon dioxide gas according to the following equation:

$$H_2O_{(g)} + CO_{(g)} \rightleftharpoons H_{2(g)} + CO_{2(g)} + 10 \text{ kcal}$$

5 moles of $H_2O_{(g)}$ and 4 moles of $CO_{(g)}$ are placed in an empty reaction vessel, the temperature is maintained at 1000°C, and the reaction allowed to come to equilibrium. After equilibrium has been established, an analysis of the equilibrium mixture indicates that 2 moles of $CO_{2(g)}$ are present.

25. What is the value of the equilibrium constant?

    A. 0.40
    B. 0.67
    C. 1.0
    D. 1.6
    E. 2.0

26. What would the value of the equilibrium constant be if the reaction were allowed to come to equilibrium at a temperature somewhat higher than 1000°C?

    A. Less than the constant for 1000°C.
    B. Greater than the constant for 1000°C.
    C. The same value as the constant for 1000°C.
    D. More data are necessary to predict the value at a temperature above 1000°C.
    E. It is impossible to predict the relative values of equilibrium constants.

Questions 27 and 28 are based on the following information.

Consider the following system at equilibrium

$$N_2 + O_2 \rightleftharpoons 2NO \qquad \Delta H = 43 \text{ kcal}$$

27. Which of the following changes will be certain to increase the concentration of the product NO?

    I. increase the temperature
    II. decrease the temperature
    III. decrease the pressure
    IV. increase the oxygen concentration
    V. introduce a catalyst

C

A. I and IV
B. II and III
C. II and IV
D. II and V
E. II, IV and V

28. At a given temperature in this system, the NO is 30% dissociated. What is the number of moles of each component present in this mixture if one mole of NO is allowed to come to equilibrium at this temperature?

A. 0.15 moles each of N_2 and O_2 and 0.70 moles of NO
B. 0.30 moles each of N_2 and O_2 and 0.70 moles of NO
C. 0.35 moles each of N_2 and O_2 and 0.30 moles of NO
D. 0.60 moles each of N_2 and O_2 and 0.30 moles of NO

29. For which of the following expressions is this equilibrium equation correct?

$$K = \frac{[SO_3]^2}{[O_2]\;[SO_2]^2}$$

A. $SO_2 + O_2 \rightleftharpoons SO_3$
B. $2SO_2 + O_2 \rightleftharpoons 2SO_3$
C. $SO_2 + 2O_2 \rightleftharpoons 2SO_3$
D. $2SO_3 \rightleftharpoons 2SO_2 + O_2$
E. $SO_3 \rightleftharpoons SO_2 + O_2$

Questions 30 to 32 require the following table of solubility product constants, for some silver salts at 20°C.

AgCl	1.7×10^{-10}
$AgNO_2$	6×10^{-4}
AgI	1×10^{-16}
$AgIO_3$	4×10^{-8}
AgSCN	1×10^{-12}

30. Of the silver salts listed above, which is the most soluble in water at 20°C?

A. AgCl
B. $AgIO_3$
C. AgI
D. $AgNO_2$
E. AgSCN

31. In a saturated solution of $AgIO_3$ at 20°C, what is the concentration of the dissolved $AgIO_3$?

    A. 16×10^{-16} M
    B. 4×10^{-8} M
    C. 2×10^{-8} M
    D. 4×10^{-4} M
    E. 2×10^{-4} M

32. To a solution containing $Cl^-_{(aq)}$, $NO^-_{2(aq)}$, $I^-_{(aq)}$, $IO^-_{3(aq)}$ and $SCN^-_{(aq)}$ ions each at 0.01 M, a few drops of 0.01 M $AgNO_3$ was added until a permanent precipitate just formed. Which silver salt precipitated?

    A. AgCl
    B. AgI
    C. $AgIO_3$
    D. $AgNO_2$
    E. AgSCN

33. A student wishes to make up 200 ml of a 0.010 M solution of $AgNO_3$. What is the maximum concentration of $Cl^-_{(aq)}$ ion that could be in the water before a permanent precipitate of $AgCl_{(s)}$ would form? Assume the solution is made at 20°C. Assume the volume does not change.

    A. 1.7×10^{-10} M
    B. 1.7×10^{-8} M
    C. 1.7×10^{-6} M
    D. 1.3×10^{-5} M
    E. 1.0×10^{-2} M

APPENDIX C

THE SKEMP TEST (SK 6)

SK6: Practice Sheet

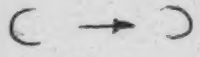
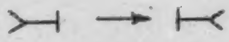
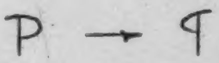
SK6: Demonstration Sheet (Operations A to J)

SK6 (PART-I) PRACTICE TEST

SK6 (PART I) ANSWER SHEET

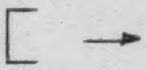
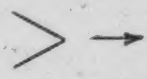
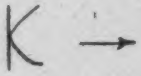
SK6 (PART II) TEST

SK6: PRACTICE SHEET

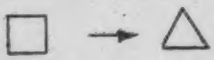
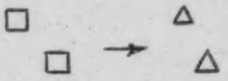
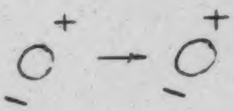
Operation 1			

In the above figures, the one on the left of each pair has been changed to the one on the right by means of the same simple operation. In other words, the above figures given three examples of a particular operation. You have to find out what the operation is, and then do the same operation to some other figures.

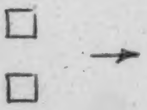
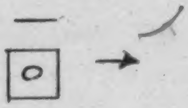
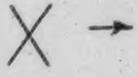
What is the operation? It is reversing from left to right. Do this on each of the figures below, and fill in the answers in the blank spaces. Check with the answers on the blackboard to make sure that you have understood.

Do Operation 1 on these.			

Here is a different operation:

Operation 2			

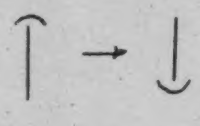
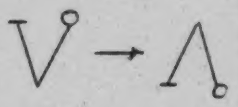
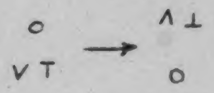
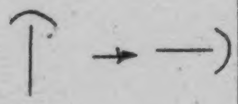
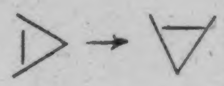
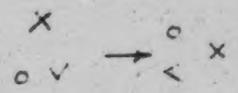
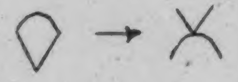
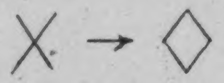
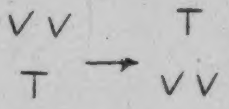
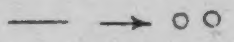
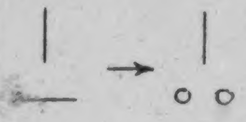
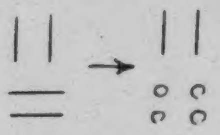
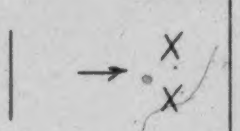
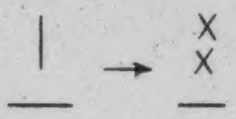
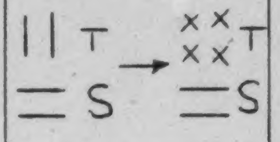
When you have found out what it is, do it on the figures below. Check with the answers on the board.

Do Operation 2 on these.			

SK6: DEMONSTRATION SHEET

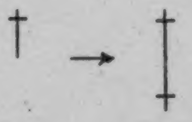
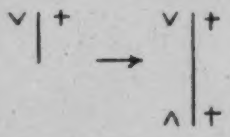
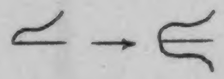
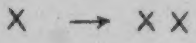
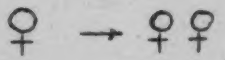
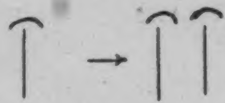
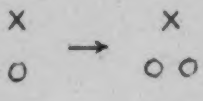
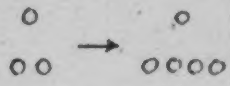
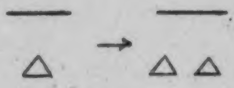
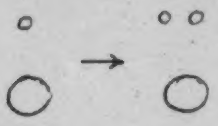
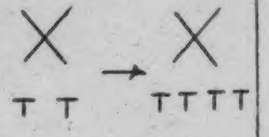
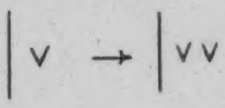
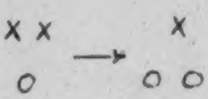
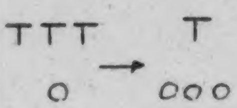
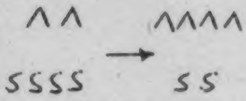
OPERATIONS A TO E

(OPERATIONS F TO J ARE ON THE NEXT PAGE)

Operation A			
Operation B			
Operation C			
Operation D			
Operation E			

SK6: DEMONSTRATION SHEET

OPERATIONS F TO J

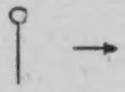
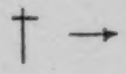
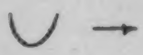
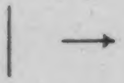
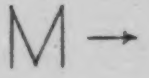
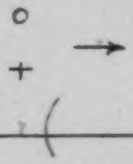
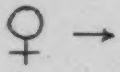
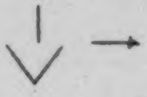
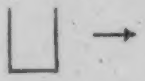
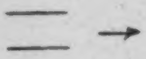
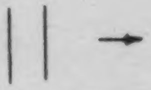
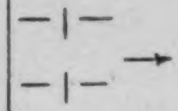
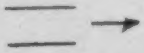
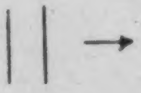
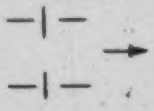
Operation F			
Operation G			
Operation H			
Operation I			
Operation J			

NAME .... SCHOOL ....
Last First Middle

AGE .... GRADE............ BOY GIRL DATE...............
Years (Circle one) Day Month Yr.

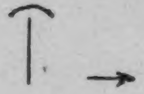
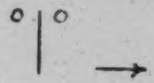
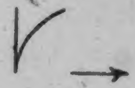
SK6: PART I

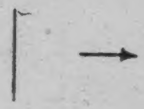
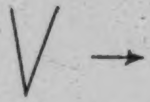
Find out the operations from the DEMONSTRATION SHEET, and fill in the answers in the blank spaces, just as you did on the PRACTICE SHEET.

Do Operation A on these.			
Do Operation B on these.			
Do Operation C on these.			
Do Operation D on these.			
Do Operation E on these.			

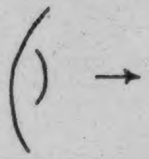
SK6: PART I

(CONTINUED)

Do Operation F on these.			

Do Operation G on these.			X oo →

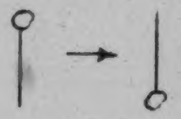
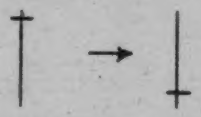
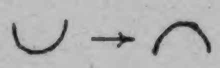
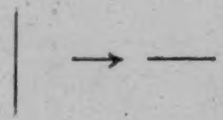
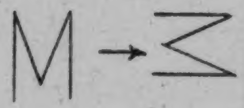
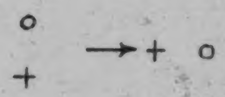
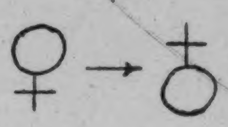
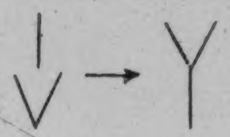
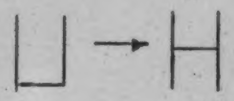
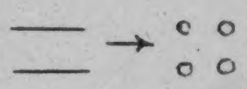
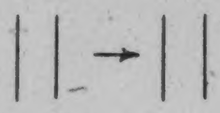
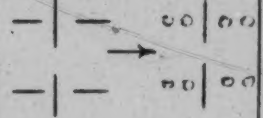
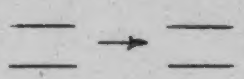
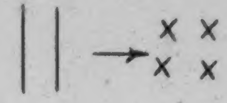
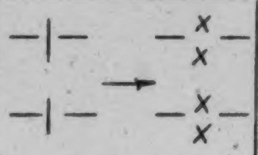
Do Operation H on these.	S T →	o + →	O + →

Do Operation I on these.	o + →	O + →	

Do Operation J on these.	x x ooo →	T S S →	ΛΛΛ /// →

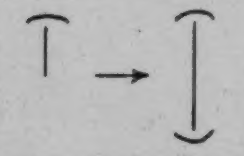
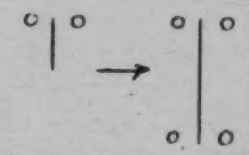
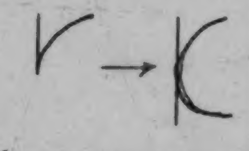
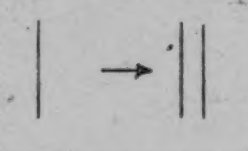
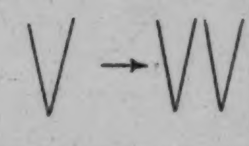
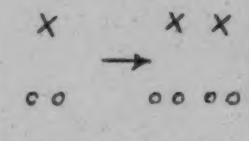
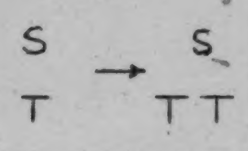
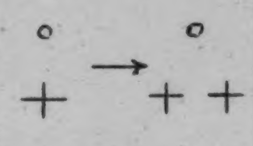
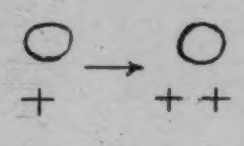
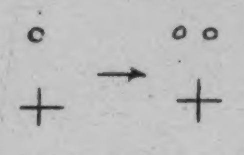
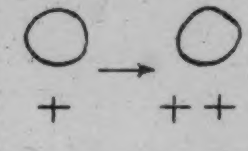
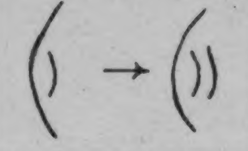
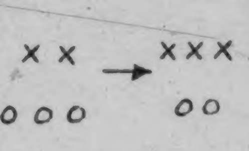
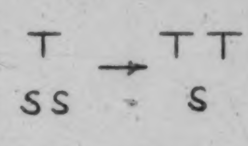
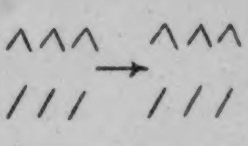
ANSWER SHEET FOR SK6, PART I

Here are the answers to the problems you did. Go through these carefully and put a tick in the right hand margin if you think that you got the whole line right. If you are not sure, ask for an explanation.

Operation A is: turn the other way up.			
Operation B is: rotate a quarter turn clockwise.			
Operation C is: interchange upper and lower parts.			
Operation D is: replace each horizontal line by two circles.			
Operation E is: replace each vertical line by two crosses.			

ANSWER SHEET FOR SK6, PART I

(CONTINUED)

Operation F is: add a symmetrical lower half.			
Operation G is: double everything.			
Operation H is double the lower part.			
Operation I is: double the smaller part.			
Operation J is: interchange the numbers.			

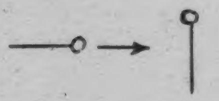
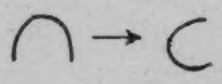
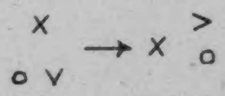
NAME.. SCHOOL..................
Last First Middle

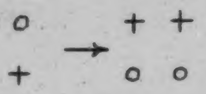
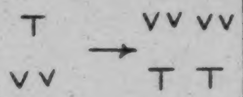
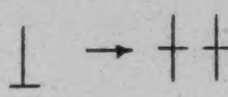
AGE............ GRADE............... BOY GIRL DATE.............
Years (Circle one) Day Month Yr.

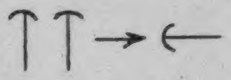
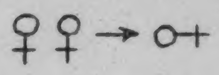
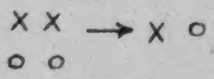
SK6: PART II

In PART II the problem is to combine the operations on the DEMONSTRATION SHEET, or to do them in reverse, or both. When combining operations, they are to be done in the order given (i.e., "Combine C and G" means "Do Operation C first and then do Operation G.")

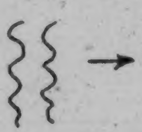
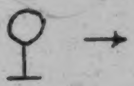
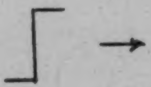
Look at the examples given below and then carry out the operations indicated on the following three pages.

EXAMPLE: Reverse B			

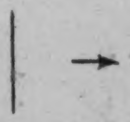
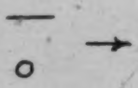
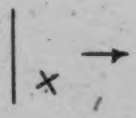
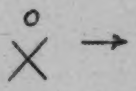
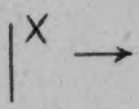
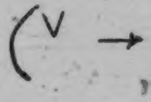
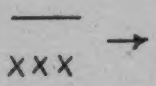
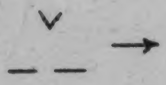
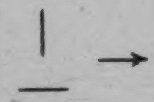
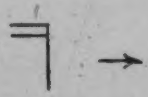
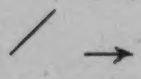
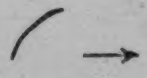
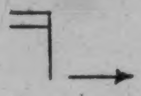
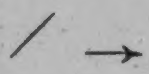
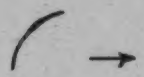
EXAMPLE: Combine C & G			

EXAMPLE: Reverse and combine G & B			

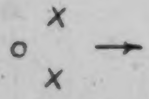
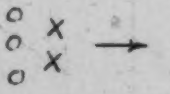
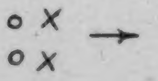
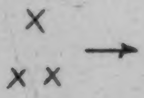
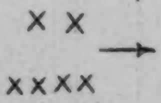
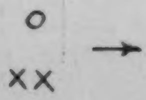
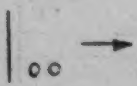
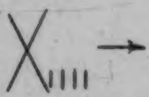
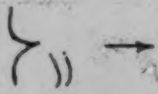
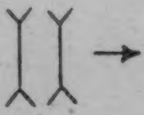
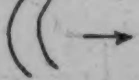
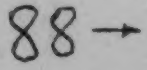
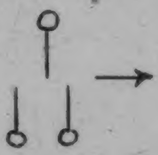
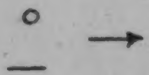
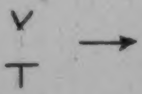
SK6: PART II

Reverse G		X X X X →	oooo →
Reverse D	o o o o →	o o v v →	o v o v →
Reverse C			(→
Reverse F	[→	0 →	X →
Reverse H	△ + + →	◡ xxxx →	— — — →

SK6: PART II

Combine E & H			
Combine A & I			
Combine D & J			
Combine B & F			
Combine F & B			

SK6: PART II

Reverse and Combine B & J			
Reverse and Combine H & E			
Reverse and Combine A & I			
Reverse and Combine F & G			
Reverse and Combine A & C			

APPENDIX D

THE COMBINATION OF COLORLESS CHEMICAL BODIES TASK (PT 1)

PT 1

Name ____________________

School __________________

Class ___________________

Date ____________________

In this experiment you are asked to reproduce the yellow coloration using all or any of the solutions provided (1, 2, 3, 4, a) as you wish. Record the steps taken to your solution in the space provided below. Investigate further to determine as much as you can about the effect and nature of each of the solutions.

What conclusions can you make from your experiments with the solutions?

SHOW YOUR APPROACH TO THE PROBLEM IN STEPS

THE COMBINATION OF COLORLESS CHEMICAL BODIES TASK (PT 2)

PT 2

Name ____________________

School ____________________

Class ____________________

Date ____________________

In this experiment you are asked to reproduce the yellow coloration using all or any of the solutions provided (1, 2, 3, 4, b) as you wish. Record the steps taken to your solution in the space below. Investigate further to determine as much as you can about the effect and nature of each of the solutions.

What conclusions can you make from your experiments with the solutions?

SHOW YOUR APPROACH TO THE PROBLEM IN STEPS.

SOLUTIONS FOR THE ADMINISTRATION OF PT 1 AND PT 2

Piagetian Task I (PT 1)

Solution 1.	A solution of Molar sulphuric acid
Solution 2.	Distilled water
Solution 3.	A solution of Normal hydrogen peroxide solution
Solution 4.	A solution of decimolar sodium sulphite
Solution "a".	A solution of decimolar potassium iodide.

Piagetian Task 2 (PT 2)

Solution 1.	Distilled water
Solution 2.	A solution of decimolar potassium iodide.
Solution 3.	Starch solution
Solution 4.	A solution of chlorine water
Solution "b".	A solution of decimolar potassium iodide.

APPENDIX E

TABLE XX

TEST SCORES FOR THE SAMPLE OF STUDENTS

N = 99

I.D.	SEX	MIT A	MIT B	CHAT	SK6 1	SK6 2	SK6 3	SK6 TOTAL	V. SCAT	Q. SCAT	TOTAL SCAT
100	M	20	21	29	13	15	07	35	44	45	089
101	M	14	22	28	13	11	08	32	54	44	099
102	M	19	24	28	14	15	08	37	56	28	084
103	M	16	19	27	13	13	07	33	46	47	093
104	M	17	18	27	14	15	06	35	54	39	093
105	M	13	21	27	11	12	06	29	59	44	103
106	M	15	21	27	14	15	07	36	48	44	092
107	M	15	22	26	13	15	07	35	54	44	099
108	M	15	22	25	11	13	01	25	49	42	091
109	M	18	20	24	14	12	08	34	50	44	094
110	M	19	24	24	13	15	07	35	52	38	090
111	F	14	20	24	08	13	04	25	54	42	096
112	M	14	20	23	11	08	10	29	42	34	076
113	M	16	21	23	14	11	04	29	57	46	103
114	F	17	21	23	14	14	07	35	48	38	086
115	M	14	21	22	14	13	07	34	44	34	078 X
116	M	12	19	22	14	13	10	37	46	41	087
117	F	14	22	21	14	10	06	30	54	36	089
118	M	15	23	20	12	12	06	30	43	30	073
119	M	11	20	20	11	14	09	37	38	35	073
120	F	13	17	19	13	12	10	35	48	37	085
121	M	12	21	19	14	13	06	33	46	43	089
122	M	08	15	19	14	13	05	32	40	26	066
123	M	15	17	18	06	12	06	24	20	11	031
124	M	12	16	18	14	14	07	35	46	39	085
125	M	13	22	18	09	10	06	25	44	35	079
126	M	17	24	18	14	11	10	35	46	35	081
127	M	12	18	17	14	14	07	35	48	29	077
128	M	11	12	17	12	07	07	26	39	35	074
129	F	09	14	17	12	12	10	34	48	41	089
130	M	12	19	16	12	11	06	29	46	44	090
131	F	17	19	16	08	13	07	28	44	34	078 X
132	M	08	16	15	12	12	07	31	44	42	086
133	F	13	11	14	08	08	07	23	46	38	084
134	M	12	15	13	14	12	05	31	49	41	090
135	M	13	18	11	11	08	03	22	53	35	088

TABLE XX (CONTINUED)

TEST SCORES FOR THE SAMPLE OF STUDENTS

X = mean scores inserted for missing data

I.D.	SEX	MIT A	MIT B	CHAT	SK6 1	SK6 2	SK6 3	SK6 TOTAL	V. SCAT	Q. SCAT	TOTAL SCAT	
136	F	15	17	17	05	10	05	20	36	31	067	
137	M	10	17	18	13	11	03	27	44	34	078	X
138	F	18	22	18	11	07	14	32	44	34	078	X
139	M	10	13	10	13	12	10	35	50	33	083	
140	M	19	19	33	08	15	10	33	54	37	091	
141	M	10	22	19	04	01	00	05	44	34	078	X
142	F	17	20	22	11	12	06	29	46	22	068	
143	M	16	21	23	14	09	06	29	39	33	072	
144	M	13	15	20	11	08	09	28	44	34	078	X
145	F	09	15	21	13	12	07	32	44	34	078	X
146	F	17	26	27	11	14	12	37	35	45	080	
147	M	09	15	14	13	08	10	31	46	29	075	
148	M	10	13	22	12	07	13	32	52	35	087	
149	F	06	13	22	07	09	03	19	44	30	074	
150	M	19	20	24	14	12	11	37	56	39	095	
151	M	18	24	25	11	13	06	30	49	45	094	
152	F	06	06	05	06	07	01	14	39	19	058	
153	M	17	26	26	14	14	07	35	41	36	077	
154	M	21	25	24	10	13	06	29	50	26	076	
155	F	14	16	18	11	06	13	30	52	35	087	
156	F	14	23	22	09	14	10	33	58	39	097	
157	F	13	14	13	13	08	07	28	48	29	077	
158	M	13	18	16	05	07	06	18	14	32	046	
159	M	13	21	16	12	10	05	27	38	26	064	
160	F	20	23	23	09	07	08	24	44	31	075	
161	F	09	16	22	05	15	03	23	42	44	086	
162	F	12	21	17	05	09	05	19	44	34	078	X
163	F	12	17	12	06	05	03	14	40	27	067	
164	F	11	14	16	08	09	01	18	44	37	081	
165	F	12	13	20	08	01	05	14	43	15	058	
166	F	08	10	19	13	09	08	30	44	23	067	
167	F	16	23	23	13	14	07	34	42	34	076	
168	F	12	20	16	13	15	13	41	44	28	072	
169	M	15	19	20	14	14	07	35	47	37	084	
170	F	15	22	20	06	08	01	15	42	20	062	
171	F	13	22	14	07	09	01	17	36	24	060	
172	F	19	26	23	13	12	03	28	26	27	053	
173	F	11	13	21	07	08	05	20	44	34	078	X
174	M	10	18	21	05	11	04	20	46	39	085	

TABLE XX (CONTINUED)

TEST SCORES FOR THE SAMPLE OF STUDENTS

I.D.	SEX	MIT A	MIT B	CHAT	SK6 1	SK6 2	SK6 3	SK6 TOTAL	V. SCAT	Q. SCAT	TOTAL SCAT
175	F	13	15	17	13	08	01	22	47	37	084
176	F	15	19	15	11	10	05	26	48	38	086
177	M	14	20	14	05	09	03	17	29	35	064
178	M	16	18	13	04	09	03	16	42	33	075
179	M	13	15	19	13	11	06	30	48	15	063
180	M	10	18	19	13	13	07	33	50	32	082
181	M	17	21	25	14	15	07	36	44	48	092
182	M	08	17	09	11	02	03	16	46	34	080
183	M	16	21	17	14	09	06	29	30	35	065
184	M	16	19	26	13	12	07	32	59	46	105
185	F	14	15	15	08	10	05	23	41	16	057
186	M	11	15	20	09	10	06	25	46	34	080
187	F	13	19	22	12	10	03	25	29	22	051
188	M	13	16	19	14	05	03	22	51	33	084
189	M	15	23	19	14	13	06	33	44	34	078 X
190	M	14	24	17	08	04	00	12	25	19	044
191	F	18	22	17	10	05	07	22	34	25	059
192	M	09	17	04	14	10	09	33	44	34	078 X
193	M	10	17	19	04	11	00	15	32	30	062
194	F	09	11	11	11	13	07	31	41	38	079
195	M	09	14	18	12	02	00	14	30	35	065
196	M	13	19	18	11	10	01	22	36	40	076
197	M	14	16	14	02	08	00	10	44	30	074
198	M	17	21	25	10	14	06	30	52	28	080

TABLE XXI

ITEM ANALYSIS OF THE MIT(A)

Mean = 13.6
S.D. = 3.3
Reliability (KR-20) = .49

Item Number	Keyed Answer	Difficulty Index	Biserial Correlation
1	A	.43	.41
2	B	.55	-.09
3	A	.31	.38
4	A	.70	.35
5	A	.83	.42
6	B	.68	.27
7	A	.27	.15
8	A	.76	.54
9	C	.51	.71
10	D	.16	.16
11	C	.49	-.01
12	B	.03	-.21
13	B	.27	.00
14	C	.80	.47
15	D	.01	.62
16	D	.02	.24
17	A	.62	.49
18	B	.70	.44
19	C	.40	.63
20	B	.83	.58
21	D	.01	.05
22	B	.43	.53
23	A	.26	.40
24	B	.80	.07
25	A	.73	.46
26	C	.43	.34
27	B	.28	.16
28	A	.54	.53
29	C	.51	.63
30	C	.29	.38

TABLE XXII

ITEM ANALYSIS OF THE MIT(B)

Mean = 18.6
S.D. = 3.9
Reliability (KR-20) = .57

Item Number	Key Answer	Difficulty Index	Biserial Correlation
1	B	.42	.29
2	A	.21	-.05
3	B	.35	.17
4	C	.23	.47
5	C	.11	.47
6	C	.23	.46
7	B	.49	.36
8	C	.16	.66
9	B	.28	.65
10	A	.52	.10
11	A	.40	-.05
12	C	.81	.59
13	C	.60	.31
14	A	.10	.61
15	A	.75	.43
16	B	.70	.38
17	B	.20	.40
18	A	.20	.37
19	B	.34	.54
20	A	.12	.47
21	A	.88	.78
22	C	.23	.49
23	C	.62	-.05
24	D	.10	.04
25	B	.15	.31
26	B	.45	.31
27	C	.63	.33
28	B	.26	.44
29	B	.27	.65
30	A	.61	.35

TABLE XXIII

ITEM ANALYSIS OF THE CHAT

Mean = 19.5
S.D. = 5.0
Reliability (KR-20) = .75

Item Number	Keyed Answer	Difficulty Index	Biserial Correlation
1	D	.35	.39
2	E	.55	.56
3	D	.84	.63
4	C	.77	.56
5	C	.60	.11
6	B	.73	.51
7	C	.62	.28
8	C	.91	.42
9	B	.76	.48
10	D	.56	.45
11	E	.70	.47
12	A	.36	.37
13	D	.79	.25
14	D	.25	.40
15	B	.52	.45
16	D	.63	.47
17	B	.75	.53
18	E	.82	.53
19	A	.64	.51
20	A	.69	.54
21	B	.80	.41
22	C	.40	.36
23	D	.72	.59
24	E	.20	.54
25	B	.49	.67
26	A	.25	.52
27	A	.64	.33
28	A	.43	.45
29	B	.92	.48
30	D	.75	.42
31	E	.41	.46
32	B	.33	.61
33	B	.37	.50